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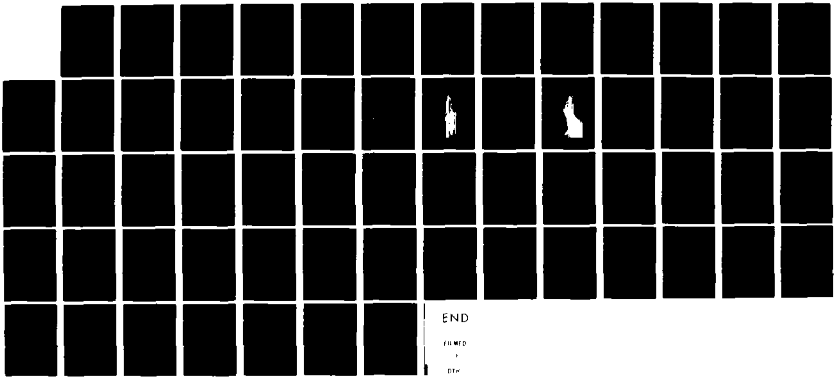

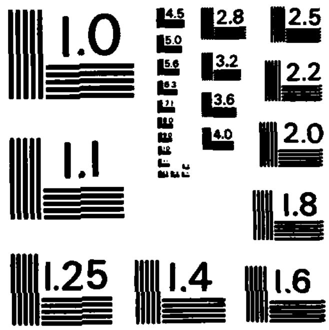

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THE INFLUENCE OF HELICOPTER OPERATING CONDITIONS ON ROTOR NOISE CHARACTERISTICS AND MEASUREMENT REPEATABILITY

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SUMMARY

Following on exploratory developments in flight-testing techniques and data-analysis procedures for helicopter external noise, extensive measurements of noise characteristics and associated flight-path data have been made by RAE on several helicopters in various operational modes, with repeated flight trajectories over longitudinal and lateral arrays of ground-based microphones under quiet airfield conditions. This analysis presents some experimental results from Lynx aircraft with standard rotor configurations, being concerned primarily with the influence of different operating procedures on both main-rotor and tail-rotor noise characteristics and on measurement repeatability; during level-flight, oblique landing-approach, and oblique take-off. Some tail-rotor near-field noise signatures have also been derived for correlation purposes, using a microphone mounted with a forward-facing nose-cone just outside the fuselage skin on the tail-boom. The scope of other noise measurements to be reported later by RAE on a Lynx with a quieter tail-rotor, a Gazelle and a WG 30 is also outlined for completeness.

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* Amplified version of presentation at the Sixth European Rotorcraft and Powered-Lift Aircraft Forum in Bristol (UK), September 1980.

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1 INTRODUCTION

The RAE Flight Research Programme on helicopter external noise is intended to help satisfy demands for minimisation of observed noise levels in respect of civil annoyance and of acoustic detectability, commensurate with operational safety and efficiency requirements (Fig 1) and for acoustic diagnosis of helicopter rotor noise leading to improvement of prediction methods. Some essential developments in flight-testing techniques and preliminary results on helicopter flight-path and acoustic-signal repeatability, for noise diagnosis and noise certification (Fig 2) were first obtained mainly using Lynx (XZ-234 and XZ-233) as reported in 1978[1,2]. Exploratory analysis also then confirmed that the external noise characteristics of helicopters are complex not only as regards spectral content and levels, but can also change markedly with the flight conditions. Such variations are particularly associated with the complicated aerodynamic operating conditions of both the main-rotor and tail-rotor and with possible flow interactions, since the rotors are mounted in close proximity to one-another and to the large fuselage or tail-cone/fin.

During the past 2 years, extensive measurements of noise characteristics and associated flight-path data have been made by RAE mainly on Lynx variants (Figs 3 and 4) on a Gazelle and on a WG 30, in various operational modes; all with repeated flight trajectories over longitudinal/lateral arrays of ground-based microphones under quiet airfield conditions. Some tail-rotor near-field noise signatures have also been obtained for correlation purposes on one Lynx (XW-837) using a microphone with a forward-facing nose-cone just outside the fuselage skin on the tail-boom. In the flight trials at RAE Bedford airfield, precise kine-tracking of the aircraft and time-coordination with the registered acoustic signals have been provided; but for other trials at the RNAS Merryfield site, only cruder spatial/time information was obtained.

This Report presents RAE experimental results obtained on three Lynx helicopters (XZ-234, XX-910 and XW-837) with standard rotor configurations, being concerned primarily with the influence of different operating procedures on main-rotor and tail-rotor noise characteristics and on measurement repeatability. In steady level flight, indicated air-speed was varied between 70 kn and 150 kn with appropriate collective-pitch changes of the rotor at normal rev/min, and rotor speed was varied between -5% and +5% of the normal operating rev/min at 120 kn air speed. Oblique landing approaches were completed at approach angles of 6°, 9° and 12° (on XX-910) using the RAE portable approach aid (PAPI). Oblique take-off trials have already been reported[1,2] on Lynx (XZ-255) and Sea King (XV-371), so only brief reference to the implications of the results need be made here for completeness.

This Report explains the flight-path and noise measurement techniques (sections 2.1 and 2.2), the scope of the flight trials in level-flight and landing-approach (sections 2.3 and 2.4), and the acoustic analysis techniques (section 3). After consideration of flight-path repeatability in level flight (section 4.1), the effects of variation in helicopter air speed and in rotor rotational speed are discussed (sections 4.2 and 4.3) primarily from extensive 1/3-octave and narrow-band analysis for the

far-field ground-microphones, but also from preliminary narrow-band analysis for the near-field tail-boom microphones. Supplementary consideration follows of the influence of variations in landing-approach angle on flight-path repeatability and noise measurements (sections 5.1 and 5.2).

2 HELICOPTER FLIGHT TRIALS

2.1 Flight-path guidance and measurement

The planning and execution of the RAE exploratory flight-research programme on helicopter external noise[1] provided valuable experience towards the development of better flight-testing techniques for noise diagnosis and noise-certification purposes under level-flight, steady-climb, landing-approach and take-off conditions. Such flight trials are carried out for preference at RAE Bedford airfield (Fig 5a&b) where very-quiet and well-controlled test conditions can be made available over reserved half-day periods. The nominated ground-track for most noise trials usually follows the direction of the main-runway with precise and clear marking of the ground-track, by the runway centre-line/edge or by marker-boards, and of its extension at entry and exit. Height is usually selected or maintained by pilot reference to the aircraft instrumentation, preferably a radio-altimeter, while a simple portable light system called PAPI provides an easily deployable aid to flying along a prescribed landing-approach slope.

At RAE Bedford, the aircraft path is tracked against time by the local kine-theodolite system using two telescope-cameras, so that subsequent automated triangulation provides data on the aircraft spatial location (within 0.3 m) and on the aircraft velocity. Off-track correction advice can also be transmitted immediately from the kine real-time on-line plot of the aircraft position in both plan and elevation (within 2 m). The test programme can be monitored continuously by radio links between the noise-measurement team-leader, and the air traffic controller. Elsewhere, in the absence of kine-tracking with automated read-out, the flight-path records are somewhat minimal, by 'still-camera' photographs of the outline of the aircraft when passing directly overhead and by visual observation of the flight-track from the runway edge.

The record of aircraft flight-condition data usually includes the variation in fuel weight state, rotor rev/min and collective blade-pitch angle, aircraft indicated air speed, altitude and outside air temperature; unfortunately, rotor-torque measurements were not available on the aircraft. In future work, it would also be useful to incorporate a helicopter 'agility instrumentation pack' giving aircraft attitude in pitch and roll, together with angular rates in pitch/roll/yaw and linear accelerations in all three aircraft axes if required. Records of local barometric pressure, humidity and wind conditions are usually provided below 15 m height by standard installations monitored by airfield meteorological staff. But the possible significance of stratified atmospheric variations due to the changes in aircraft height during climb-out and descent deserves future study.

2.2 External noise measurement techniques

The mobile laboratory developed by RAE for outdoor acoustic trials has been employed on site for all these flight tests. The acoustic data recorded on magnetic tape and the positional data from the kinetheodolites at RAE Bedford are synchronised by registering a 1 kHz pulse-train (modulated to 10/s) on one track of the tape-recorder and by providing a simultaneous imprint on the kine film, ensuring a common time marker throughout each test run. Thus the flight-path data allows not only evaluation of deviations from the nominated path, but also permits direct scientific correlation of the noise source range, aircraft velocity, noise source emission and reception angle for each noise data sample analysed. The external noise measurements for helicopters were first made with 1 inch pressure-response microphones (23 mm diameter), but for logistic and reliability reasons ½ inch microphones (12 mm diameter) have recently been preferred; these are connected via pre-amplifiers and microphone power supplies to the 14-track FM magnetic-tape recorder. This system has a flat frequency response (within ±1 dB) extending from 2 Hz or 6 Hz to 10 kHz, and a dynamic range of 50 dB.

In the RAE array, up to 12 microphones are normally distributed along the flight-track and to both sides, as of interest at the time. Ideally these microphone locations are spaced at least 50 m apart, so that the individual microphones can be expected to give statistically uncorrelated signals for frequencies above 10 Hz. The first array (Fig 5b) used for most of the helicopter noise trials at RAE Bedford (Lynx XZ-234/XZ-233/XX-910 and Gazelle) differs from the second array (Fig 6) used at RNAS Merryfield (Lynx XW-837) in 1979 and subsequently at RAE Bedford (WG-30) in 1980. The change to a transverse row of seven microphones at 75 m intervals was made primarily to ensure a better lateral distribution for directivity considerations, though with some sacrifice of repetition along the flight direction and hence of achievable statistical confidence.

For scientific research on helicopter and aeroplane noise at low to moderate frequencies, the conventional certification requirement for microphones at 1.2 m height above grass is not acceptable because of variability of ground-reflection effects, while the possible ideal of buried microphones with their diaphragms flush-mounted in a large smooth area presents both installation and maintenance problems. Hence the RAE has preferred to use ground-level microphones over the past 8 years, with the casing laid simply on a large concrete area of runway or hard-standing (not on grass), with the microphone diaphragm in a vertical plane facing towards the flight-path, and with a hemispherical foam windshield (Fig 7). Thus the microphones are orientated so that there is grazing incidence under the flight track and incidence corrections are made for side-line positions. For the ½ inch pressure-response microphones nor normally used, there is no significant distortion of noise spectra from ground reflections for frequencies up to at least the 3.15 kHz 1/3-octave band, and in practice this range may be doubled. The recorded noise levels are consistently augmented then by 6 dB relative to free-field values. In the British temperate climate, no micro-meteorology effects have been found on such ground-level microphones, while in more extreme temperatures 1.2 m height microphone conditions could equally be affected. For compatibility with civil operation

requirements, a few microphones are placed at the official certification height of 1.2 m above the ground surface; then the relevant measurement and analysis responsibility is taken by Westland Helicopters Ltd whenever feasible.

For tail-rotor near-field measurements in flight, a ½ inch pressure-response microphone has been mounted when practicable with a forward-facing nose-cone just outside the tail-boom side-wall so that the diaphragm measured external acoustic pressures, at a location slightly forward of the tail-rotor disc area (Fig 8). The complexity and interpretation of such off-surface measurements is still under exploration, and more extensive arrays of fuselage-mounted external microphones are being examined currently on a propeller aircraft. Such near-field acoustic data is stored by an on-board magnetic-tape recorder, and experience indicates the desirability of an additional channel for voice-recording of flight information.

2.3 Level flight trials

The exploratory level-flight trials already discussed in Ref 1 were flown at RAE Bedford airfield in July 1977, using a RNAS Lynx (XZ-234) with the recommended normal value for the main-rotor rotational speed (N_R), namely 320 rev/min - designated 102.5% on the diagrams*. At each of four air speeds (70, 90, 120 and 138 kn IAS) and at two heights (150 m and 300 m), three runs were made in each direction along the nominated linear path (Fig 5b), over a distance of about 1 km before and after the central microphone array. This ground track, though parallel to the main runway, was offset over grass some 50 m laterally from the runway edge to allow additional microphones operated by Westlands to be positioned at certification height (1.2 m) above grass, while retaining the RAE microphones at ground-level on available concrete areas under the flight-path and to either side. Over the ½-day test period the wind remained at about 10 kn from 45° astern of starboard or 45° ahead of port according to the flight direction. The Lynx weight varied by only 2% during each set of repeats at a prescribed height and air speed, and not more than 10% overall.

Supplementary level-flight trials at 120 kn IAS and 150 m height were made at RAE Bedford in August 1978, using a RAE Lynx (XX-910) then available, but with variations of the rotor rev/min from the recommended normal N_R (102.5%) to 5% below and 5% above this, the maximum deviations permitted. Two runs were made in each direction over the same flight track and ground-microphone array as before, accepting similar wind and weight variabilities.

Subsequent comparative level-flight trials, on a WHL Lynx (XW-837) with standard and quiet tail-rotor configurations in April 1979, had to be carried out at RNAS Merryfield for aircraft logistics reasons. There, the ground-track was along the southern edge of the main runway, while the RAE ground-level array comprised some seven microphones spaced at 75 m intervals laterally along a concrete cross-runway, plus an extra duplicate microphone under the flight-track (Fig 6). The helicopter was again flown along the nominated linear track, maintaining 150 m altitude over a distance of 1 km before and

* This complies with the Firm's definition of Lynx operational rotor-speed at the time, arising from historical technical reasons.

after the microphone array, with two runs in each direction at constant air speeds of 70, 90, 120 and 150 kn IAS, for the rotor at normal rev/min (102.5%). Supplementary runs were likewise completed at 120 kn IAS, with variation of rotor rev/min to 5% below the normal and to 2½% above, as permitted on this aircraft. The variation in Lynx weight during each set of four repeats was again negligible and the deviation in weight over the whole exercise with the standard tail-rotor configuration discussed here did not exceed 10%, though wind speeds as high as 13 kn had to be accepted to complete the trials in the 2 h period allocated.

2.4 Oblique landing-approach trials

Some quick comparisons of landing-approach noise and measurement repeatability at different approach angles were first attempted using a RNAS Lynx (XZ-233) at RAE Bedford in October 1977. Appreciable deviations from the nominated ground-track, parallel to and offset from the concrete main runway (Fig 5a), occurred in the absence then of special ground markers other than the microphone array itself. Also kine-tracking over the long approach distances was not possible at that time due to deterioration in visibility during the available test period. A more precise series of landing-approach studies was therefore undertaken when a RAE Lynx (XX-910) became available for flights again at RAE Bedford in August 1978, employing the PAPI two-colour system for guidance in the vertical plane, and five large ground-markers* spaced at 500 m intervals for additional guidance in the horizontal plane. Each steady landing approach was started at about 1 km from the RAE microphone array (Fig 5b), with the touchdown point (PAPI location) chosen so that the aircraft should pass over the datum microphone position (No.1) at 120 m height. Three or four repeat runs were made for each of the three approach angles, 6° (at 70 kn), 9° (at 70 kn) and 12° (at 50 kn); the aircraft approach speed was selected by the pilot as that most appropriate for the high approach angle, from safety and steady-flight view points.

Complementary landing-approach trials were also completed on a Gazelle (XW-846), made available locally the same day, again at all three landing-approach angles and with guidance from the PAPI and ground-markers as described. No details of these Gazelle results can yet be quoted since their data reduction has still to be completed.

3 NOISE DATA ANALYSIS TECHNIQUES

RAE noise-testing experience with a wide range of aircraft over the past decade has stimulated complementary integration and extensive validation of relevant hardware and software for noise-data reduction and interpretation.

Each far-field noise track on the magnetic-tape recordings from the flight tests is first replayed through a loudspeaker system to check aurally for any extraneous noise interference on the analogue signal, such as unwanted bird song! At the same time, weighted noise-time histories of each overflight are obtained by replaying the signal

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* Each simple ground marker comprised a pair of boards (2 m high × 1 m wide) inclined back to back at 60° to the horizontal, and painted in day-glow orange.

through a measuring amplifier containing the appropriate weighting filter, and thence into the sound-level recorder. The amount of noise spectral analysis required for each overflight and each microphone position is then determined by examination of the relevant plots of noise-time history and of flight-path data from the kine-tracking records. 1/3-octave analysis is then achieved by feeding the analogue signal through a real-time analyser into an on-line computer with disc storage, which controls the spectral analyser so as to obtain sequential slices of pre-selected duration; currently ½ s integration times are used. The resulting spectral data is tabulated by lineprinter and plotted automatically with pre-selected scales.

With the noise data reduction system as now developed (Fig 9) a range of calibration factors can be introduced into the computer at this stage. These include the microphone frequency-response corrections and directional-response corrections which require calculation of emission-time coordinates, plus a ground-reflection factor which here involves a reduction of 6 dB in the measured levels to obtain free-field values. The values of Overall Sound Pressure Level (OASPL), A-weighted sound level L_A, Perceived Noise Level (PNL), and Tone-Corrected Perceived Noise Level (PNLT) may then be computed and plotted for each sequential time-interval. Moreover, for consistent comparisons of aircraft noise, there is the further facility for adjusting the 1/3-octave spectra and the overall levels to correspond to a datum flight-path and standard atmospheric conditions. The calculation culminates in the derivation of the value of Effective PNL, using the discrete ½ s noise samples for the period between the points 10 dB - down from peak PNLT, for each flyover and microphone position. Tabulated outputs of spectral and total noise levels are produced on a line-printer, and frequency spectra can be plotted automatically.

The noise data analysis techniques for the near-field measurements on the aircraft take advantage of the equipment mentioned above but can be much simpler because, with the fixed propagation path, long noise time-histories of spectral or total levels are not required. Moreover, the steady recording conditions maintained at each microphone (typically for 30 s) allow a long period for reliable signal integration (at least 25 s), which ensures a high level of statistical confidence without repeat runs and without multiple complementary microphones, even at very low frequencies.

To permit more rapid detailed study of noise spectra as regards discrete frequency content, our narrow-band frequency analysis capabilities have also been much improved recently. Typically, digital analysis with centre-frequency intervals of 3.1 Hz yielding an effective bandwidth of 11 Hz can be provided over the total frequency range - 0 to 1.6 kHz of current primary interest; again automatic plotting of the spectra is available. For narrow-band analysis of near-field and far-field noise, sample lengths of about 0.32 s and 0.16 s duration respectively are presented employed. Detailed time histories of sound-pressure level have also been plotted automatically for such noise sample lengths.

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4 LEVEL-FLIGHT RESULTS

4.1 Flight-path repeatability

In our earlier paper (Stresa, 1978) [1], exploratory results on Lynx helicopter trajectories in level-flight and in take-off were analysed with particular reference to their adequate repeatability for noise diagnosis purposes and noise-certification requirements. This Report also provided useful technique recommendations for further trials, though expediency has restricted the immediate implementation of them all.

Here we can usefully recall the 25 level flights made with Lynx XZ-234 at 150 m height over a grass track parallel to and offset laterally by 50 m from the main runway edge, with only two marker boards under the track. In the vicinity of the microphone array all these overflights except one were within one main-rotor diameter (12.8 m) laterally of the nominated track, *ie* the aircraft flew over at an angular deviation of less than 5^{o} from the vertical sight-line. Of the poorer runs with a lateral offset exceeding 5 m in the microphone vicinity (angular deviation $>2^{o}$), seven were to starboard and only one to port. Furthermore over the nominated linear track length of 1.8 km, one level-flight again exhibited a mean value of the lateral offset exceeding one rotor diameter, while some half of the flights had a mean offset less than one-half the rotor diameter. Statistically, the standard deviation of the lateral offset for all flights was 5.4 m with one-quarter of the passes being below 3 m. In the vertical plane the standard deviation was 4.2 m with again one-quarter of the passes below 3 m.

Despite the later provision of five track markers on grass for the 12 level-flights made with Lynx XX 910, all these passes were offset noticeably to port (Fig 10), five of them by more than one rotor diameter laterally abreast of the datum underpath microphone. Over the test track length of 1.8 km, four of these flights exhibited a mean absolute lateral offset again exceeding one rotor diameter. Statistically the standard deviations of the lateral offset was 3.4 m, ranging for individual flights between 1.5 m and 4.5 m. In the vertical plane the value was 5.6 m with a maximum of 6 m and half the passes less than 4.5 m.

For more recent level-flights with Lynx XW 837 at RNAS Merryfield (Fig 6), only still photographic records were available from an upward-pointing camera (provided by WHL) close to the central datum microphone. All but one of the 16 passes photographed had a flight-path offset (northwards) from the nominated track along the southern runway edge. Apart from two gross errors (>30 m off track), all but one pass lay within 5 m of the mean lateral-offset. Unfortunately, this aircraft was not fitted with a radio-altimeter and the mean of the measured altitudes was found to be 180 m, all passes being within ±7% of this value, rather than around the nominated 150 m height.

These further Lynx trials, and other trials on different helicopters now suggest that further elaboration of the flight-path control techniques would be profitable, at least for noise research requirements. Certainly there is need for better holding of lateral position over the specified track and even of height, particularly when side-line noise measurements are important. Admittedly, when kine-tracking time-histories are available, the deviations in distance from the aircraft to the measurement microphones

(at noise-emission time) can be adequately corrected for; appropriate corrections are incorporated in our latest data-reduction computer program. However, related angular deviations requiring directivity corrections to sound intensity are less straightforward, particularly since complex main-rotor and tail-rotor sources are involved. Where the measurement technique utilises microphones located over concrete, flight along the runway centre-line is recommended, with appropriate comment on the accuracy of track at the start and end of each measurement run.

4.2 Effect of air speed on noise

The data presented in this section is 'as measured' in that no corrections have been applied for distance, atmospheric conditions, microphone directional characteristics and signal enhancement by ground reflection. Microphones under the aircraft nominal track usually record their peak overall noise levels when the aircraft is almost directly overhead. The variation of overall noise parameters with aircraft speed is illustrated by Fig 11a&b. In particular, the peak PNL values for the Lynx aircraft 837 and 234 show little change between 70 kn and 90 kn, but exhibit a substantial rise of some 8 dB between 90 kn and 150 kn, with the rate of rise itself increasing with air speed (Fig 11b).

For meaningful discussions of the influence of flight conditions, or of differences between aircraft, more detailed consideration of the distribution of sound-pressure levels across the frequency range (tones and broad-band noise) is needed. Otherwise comparisons merely in terms of overall noise-level parameters, with some preference as regards subjective frequency weighting, can be misleading. Fig 12 gives 1/3-octave spectra shapes at the peak PNLT position, and at the '10 dB down' points when the aircraft is approaching and receding in level flight. Reference to the 1/3-octave levels for Lynx 837, when overhead at the lowest air speed (70 kn), shows near equal sound-pressure levels for the two main-rotor tones at its first-harmonic frequency R_1 and its second-harmonic R_2 (25 Hz and 50 Hz bands); and for the tail-rotor at its first-harmonic frequency T_1 (125 Hz band). Then, as air speed is increased above 120-150 kn, this unweighted noise spectrum becomes dominated by the main rotor with the level of R_1 some 5 dB above that of R_2 and some 10 dB above T_1. Additionally, there is a rise in the apparent 'broad-band noise' part of the 1/3-octave noise spectrum between 315 Hz and 1.6 kHz, a region associated with the main and tail rotor flow interaction.

Although Lynx 234 has constructionally identical rotating components to the Lynx 837 just discussed, it produces spectra with tones whose relative values can be similarly ranked but with absolute levels some 2 dB higher, while the 'broad-band noise' region at the higher frequencies is little changed. Application of conventional subjective weighting to such spectra effectively removes the contribution of the main-rotor tones from PNL and L_A levels. Indeed the peak L_A levels of the two aircraft are virtually identical above 90 kn (Fig 11a). However, the differences in tail-rotor tones can explain the clear differences in the PNL values, which become even more marked when tone corrections are added to provide PNLT comparisons (Fig 11b).

Narrow-band frequency analysis performed on the recording from the microphone under the nominal track of Lynx 837 (Fig 13) show that the main-rotor is clearly

detectable in the forward-arc of the approaching aircraft up to the seventh harmonic, while only the fundamental frequencies of both main and tail-rotors are outstanding with the aircraft receding. Similar analyses at peak level (under track) for the full range of aircraft speeds confirm that the variation with air speed of the level of the predominant main-rotor tones (Fig 14) reflects the variation with speed of the overall sound pressure level derived from the unweighted 1/3-octave bands (Fig 11a); the main-rotor first harmonic R_1 and second harmonic R_2 remain close in value throughout the speed range. The variation of the tail-rotor signal (dominated by T_1), while less pronounced, is similar in-pattern with a minimum value at about 90 kn air speed. Further narrow-band analysis of the far-field noise measurements is in hand, with special reference to comparisons between standard and quiet tail-rotor configurations tested on this aircraft.

Sample pressure-time histories directly corresponding to the frequency analyses just discussed (Fig 13) show the main- and tail-rotor impulses distinctly for the approaching aircraft. However, such impulses are not clearly defined for the receding aircraft.

The unweighted sound-pressure levels at the tail-boom microphone in the noise near-field are dominated by the second harmonics of both main and tail rotors throughout the aircraft speed range (Fig 15a). For both rotors all the prominent harmonics (up to the fourth) exhibit a near-linear rise in tone level with increasing air speed up to 120 kn followed by a fall at 150 kn (Fig 15b). This is believed to be a genuine effect, possibly associated with radical changes in character or directivity which are not yet properly understood. Evidence elsewhere also shows a progressive roll-off in these near-field tone levels from 120 kn upwards to 150 kn.

The far-field lateral distributions of peak overall noise levels corresponding to peak PNLT directly under the flight-path are shown in Fig 16 for Lynx 837 and 234 over the range of air speeds. Above 90 kn the curves drawn for Lynx 837 exhibit a bias towards higher noise levels to starboard, which is the side of the advancing main-rotor blade, and of the tail-rotor wake. This bias appears most pronounced at about 120 kn air speed and 150 m lateral distance (45° inclination), where the level on the starboard side is some 3 dB higher than the corresponding level to port. The behaviour is quite consistent on each of the four repeat flights. Although this bias is not seen on the PNL-weighted lateral distributions of Lynx 234, it is nevertheless still apparent on the lateral distribution of linear OASPL (Fig 16a); the removal of the main rotor tones by weighting in the calculation of PNL makes the distribution much flatter than that of linear OASPL. It may be noted that, where appreciable variations in level (order 2 dB) occurred between repeat runs at any one air speed, the levels recorded across the microphone array all tended to move together, implying little change in directivity.

The results before and after overhead for Lynx 837 confirm the expected smaller variation in the lateral distribution of sound level across the microphone array compared to the near overhead position. Fig 17 shows that for the approaching aircraft at 70 kn the predominant unweighted tone to port is the main-rotor second harmonic R_2, while under track it is R_1 and to starboard the tail-rotor fundamental T_1 has a near equal

value. As speed is increased, R_1 becomes equal in value to R_2 and T_1 has a value equal to or slightly below these. Subjectively-weighted spectra, and correspondingly the human ear, will give predominance to T_1. In the rearward arc, R_1 is the predominant feature of the unweighted spectra for speeds exceeding 90 kn.

Examination of the noise time-histories from the under-track microphone, for which examples are plotted for Lynx 837 (Fig 18), show the predictable rise in level with increased speed over the whole of the measurement period, and correspondingly a marked increase in the rate of rise in noise level as the aircraft approaches overhead. The double peak usually present in both the PNL and L_A time-histories is much reduced or entirely absent in the history of PNLT, due to the influence of the main-rotor second harmonic R_2 which is of sufficient level to exert a substantial tone correction overhead, but which declines rapidly in value after overhead.

4.3 Effects of rotor rotational speed

The results for Lynx 837 in this section are necessarily 'as measured values' (see section 4.2). But, with kine-tracking data available to permit more elaborate data for the nominally identical Lynx 910, these latter results have been corrected to a datum flight-path at 150 m altitude and to standard-day conditions, while still retaining the enhancement (6 dB) due to ground reflection. In the unweighted spectrum of Lynx 837 (Fig 19a) when near overhead, the levels of the main-rotor first harmonic R_1 and of the tail-rotor first harmonic T_1 remain close in value for all the three rotor speeds investigated. In contrast, for Lynx 910 (Fig 19b), the level of R_1 is some 3-4 dB lower than T_1 at 97.5% N_R, with R_1 rising to an equal level at 107.5% N_R. The spectral levels towards the higher frequencies are greater with Lynx 910 than with 837 for the two lower rev/min settings (97.5% and 102.5% N_R); this accounts for the increased separation of the L_A and PNL curves noticeable at these two rotational speeds (Fig 20).

The reduction in noise on level approach, as compared to overhead, is greater at the higher frequencies than for the lower frequency tones for both aircraft (Fig 19a&b). While T_1 is lower on Lynx 837 than 910 during level approach, both T_1 and T_2 are of the same order as R_1 and R_2 for Lynx 910. For the receding aircraft, Lynx 837 has R_1 as the predominate unweighted tone level; but, on Lynx 910, T_1 becomes equal to or of greater level than R_1.

Comparison of the lateral distributions at peak PNL levels (Fig 21c) shows that Lynx 837 begins to display a bias to starboard (the advancing blade side) when rotational speed is increased above 97.5% N_R while Lynx 910 exhibits a noticeable bias at all three rev/min. The PNL and L_A levels (Fig 21b) are especially affected by changes in the levels of the spectral bands between 400 Hz and 1.6 kHz, which contain the rotor interaction noise and which rise in level by some 4 dB over the range of increasing rotor speed as shown here for Lynx 837 (Fig 19a).

The influence of rotational speed on rotor noise is further illustrated by narrow-band analysis of the tail-boom microphone signal recorded on Lynx 837 (Figs 22 and 23). The small variation in main rotor noise levels (1 dB in R_2) contrasts with the larger (>4 dB) increase in T_2 over the range of rotational speeds. The spectral plots (Fig 23) show a progressive increase in the number of the tail-rotor harmonics from four to six, together with a rise in level of these tones.

These tail-boom microphone results, together with additional narrow-band and 1/3-octave analysis for ground microphones will be discussed more fully in a later paper covering comparisons between a standard and a quiet tail rotor fitted to Lynx 837.

5 LANDING APPROACH RESULTS

5.1 Flight-path repeatability

Landing approaches were made at 6^o, 9^o and 12^o with Lynx 910 using the PAPI lighting aid referred to in the Introduction and described in our earlier paper[1]. The stipulated height over the microphone array had to be adjusted from the datum 150 m due to the logistics requirements associated with power supplies and to ensure kine-sight of the aircraft at these low altitudes. But all quoted noise data has been corrected here for a constant clearance height of 150 m over the datum microphone. At all three approach angles, the vertical profile is close to the desired descent path (Fig 24). For 9^o descent, only one of the four examples shown here diverges appreciably from the stipulated height while the four examples at 6^o and two at 12^o are all satisfactory. As for level flight, the lateral deviation is again unsatisfactory, so lateral correction of the flight-path during such runs by active guidance or radio-transmission corrections appears advisable. However, it is possible that the corrective actions resulting from such instructions may themselves cause unpredictable changes in noise levels.

5.2 Noise measurements

The ground microphone measurements made under the nominal track (Fig 25) show that, when corrected to the same height, the peak OASPL decreases only by a small amount (some 1.5 dB) from the 6^o to the 12^o descent angle; but the level of L_A reduces much more substantially (by as much as 5 dB). While the PNL and following curves again show a small fall in level above 6^o approach angle, there appears to be little change between 9^o and 12^o. Overall it will be appreciated that the changes in noise level with approach angle can vary appreciably with the preferred noise index, while these levels will again depend on the particular aircraft characteristics.

The tail-rotor noise is no less significant in landing-approach than in level-flight, with unweighted tone levels within 1 dB or 2 dB of the level of the first harmonic R_1 of the main rotor (Fig 26).

In the lateral distributions (Fig 27) the highest level again exhibits a bias to starboard above the 6^o descent angle. At 12^o the repeatability and reliability of the data must be treated as limited, particularly since only two approaches were attempted and these were near autoration conditions.

6 CONCLUDING REMARKS

The foregoing analysis has presented a substantial amount of experimental results from Lynx aircraft with standard rotor configurations, covering three individual machines, each with nominally the same dynamic components, but differing slightly in ancillary gear (naval or utility) and in development status. The present studies have been concerned primarily with the influence of different operating procedures on

measurement repeatability and on both main-rotor and tail-rotor noise characteristics. In particular specific variations have been attempted separately of forward speed, rotor rotational speed, and angle of descent.

It may be concluded that, in future experiments, the repeatability of the aircraft flight-paths would probably be best assured by nominating a clearly marked centre-line on a paved runway strip as the ground track, rather than a runway edge or a line of markers over grass. In addition to the centre-line providing an easily acquired aid to alignment during approach and overflight, the pair of runway edges (equally offset from the desired track) supply additional guidance irrespective of the direction of flight along the runway; particularly when close view of the centre-line may be obstructed by solid protruding noses as on Lynx. This should help eliminate the natural bias to one side of the track now apparent in the positional data from the tracks chosen previously.

The practice of feeding flight-path corrections to the pilot during the period of noise measurement, as frequently employed on acoustic trials with fixed-wing jet aircraft, seems much less suited for use with helicopters. Any gains in repeatability achieved by more consistent location of the aircraft, relative to the measuring points, are more likely to be outweighed for a helicopter by the more significant changes in source-noise signature associated with flight-path control requirements. During level flights the provision of a radar altimeter is highly desirable, particularly where lateral noise measurement locations are of concern.

The relative values of the main-rotor contribution to the unweighted overall sound pressure level increase at the higher speeds, as can be inferred from comparison with the slopes of the subjectively - weighted curves for which the main-rotor contribution is secondary. However there is a significant contribution to the weighted levels from the flow interaction of the main-rotor wake on the tail-rotor at higher speeds. In the near field, as measured by the tail-boom microphone, it is of interest to note the reduced noise levels at the highest air speed which must imply a change in the rotor flow interaction or in the noise directivity.

Our level-flight studies have confirmed quantitatively the suspected variation in the noise levels between individual Lynx aircraft. Under-track measurements of XX-910, when compared with XVV-837 at standard and reduced rotor speeds exhibit higher values of subjectively weighted overall sound-pressure levels, and hence of aurally perceived noise level, mainly because of the higher contribution of tail-rotor noise to the spectrum of the former aircraft. Except at low air speed, an invariable bias appears in the lateral overall sound pressure level distributions for both aircraft, with the higher levels manifest on the side of the advancing blade and the tail-rotor wake.

For the Lynx a reduction in noise levels on landing approach is here achieved by increasing the angle of descent to 9° compared with 6° (4 dB(A), 2.5 EPN dB decrease). But a further steepening of the descent angle to 12°, where of practical necessity the speed was reduced to 50 kn whereas the rotor rev/min tended to rise, is less advantageous on anything other than a simple L_A assessment. More generally, any bias in the lateral distribution might be of significance in the choice of landing approach path.

Additional comments on measurement repeatability and further clarification of rotor-noise characteristics under practical operating conditions should be provided by our present analysis of RAE noise measurements on Lynx XW-837 in standard and quiet tail-rotor configurations and on the prototype WG 30.

REFERENCES

No.	Author	Title, etc
1	J. Williams M.R.P. Law	Helicopter flight-path and acoustic signal repeatability for noise diagnosis and noise certification. Fourth European Rotorcraft Forum, Paper 54 (1978), RAE Technical Memorandum Aero 1773 (1978)
2	M.R.P. Law J. Williams	Exploratory studies on helicopter take-off repeatability for noise certification procedures. RAE Technical Memorandum Aero 1750 (1978)

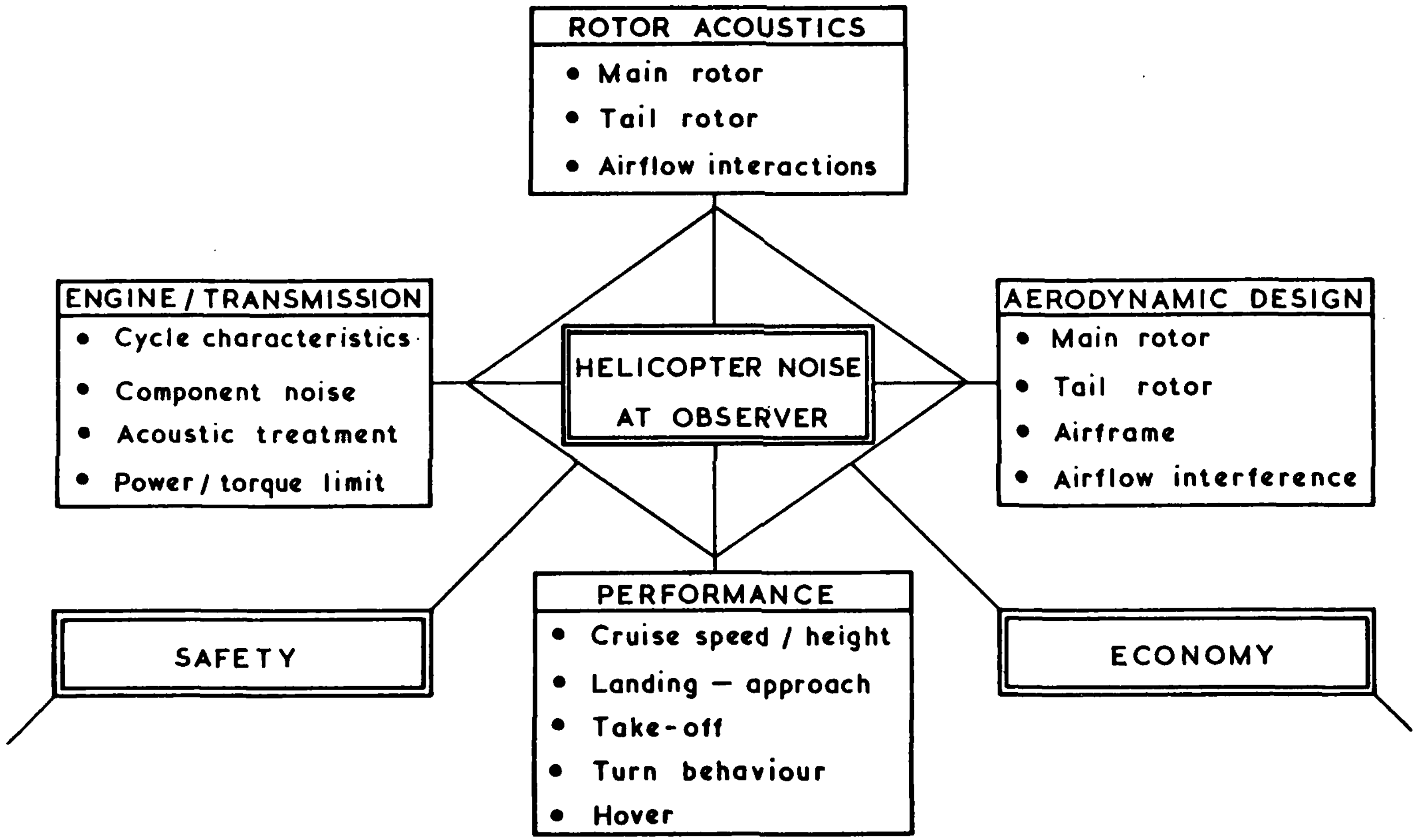

Fig 1 Helicopter design factors influencing noise

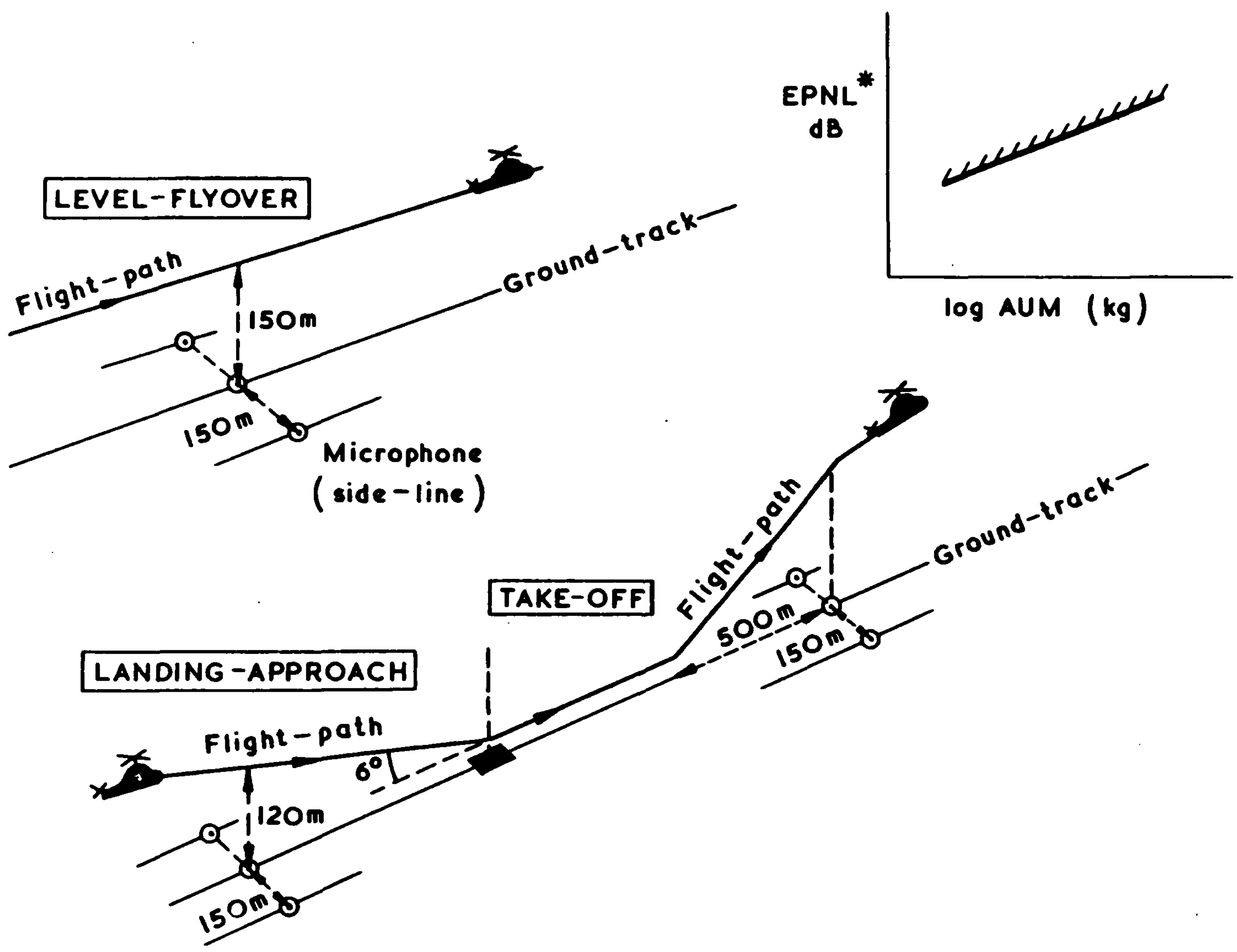

Fig 2 Helicopter noise-certification framework (1978)

Fig 3a Naval Lynx XX910

Fig 3b

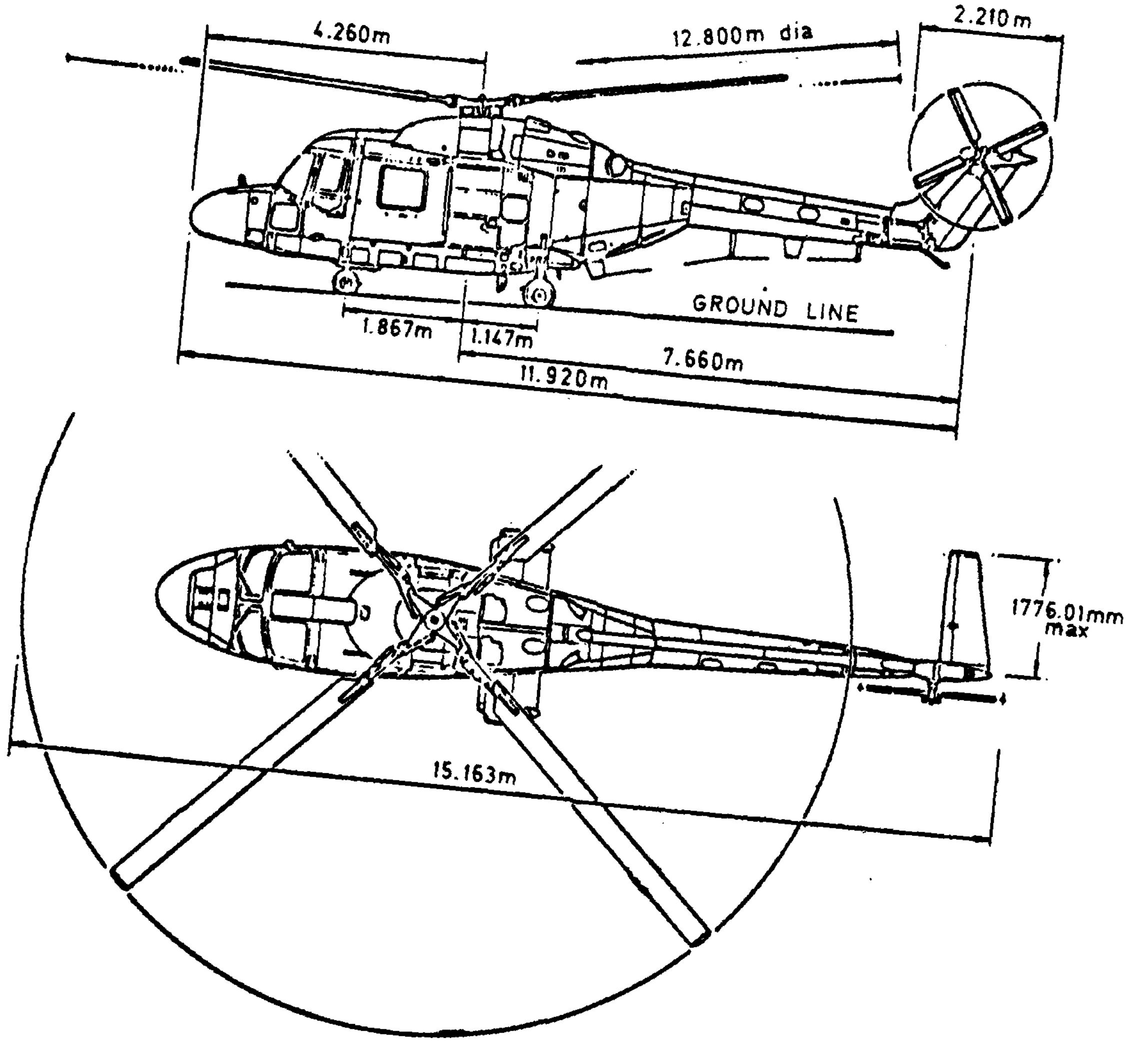

Fig 3b Naval Lynx: general arrangement (as XX910)

Fig 4 Utility Lynx prototype (as XW837)

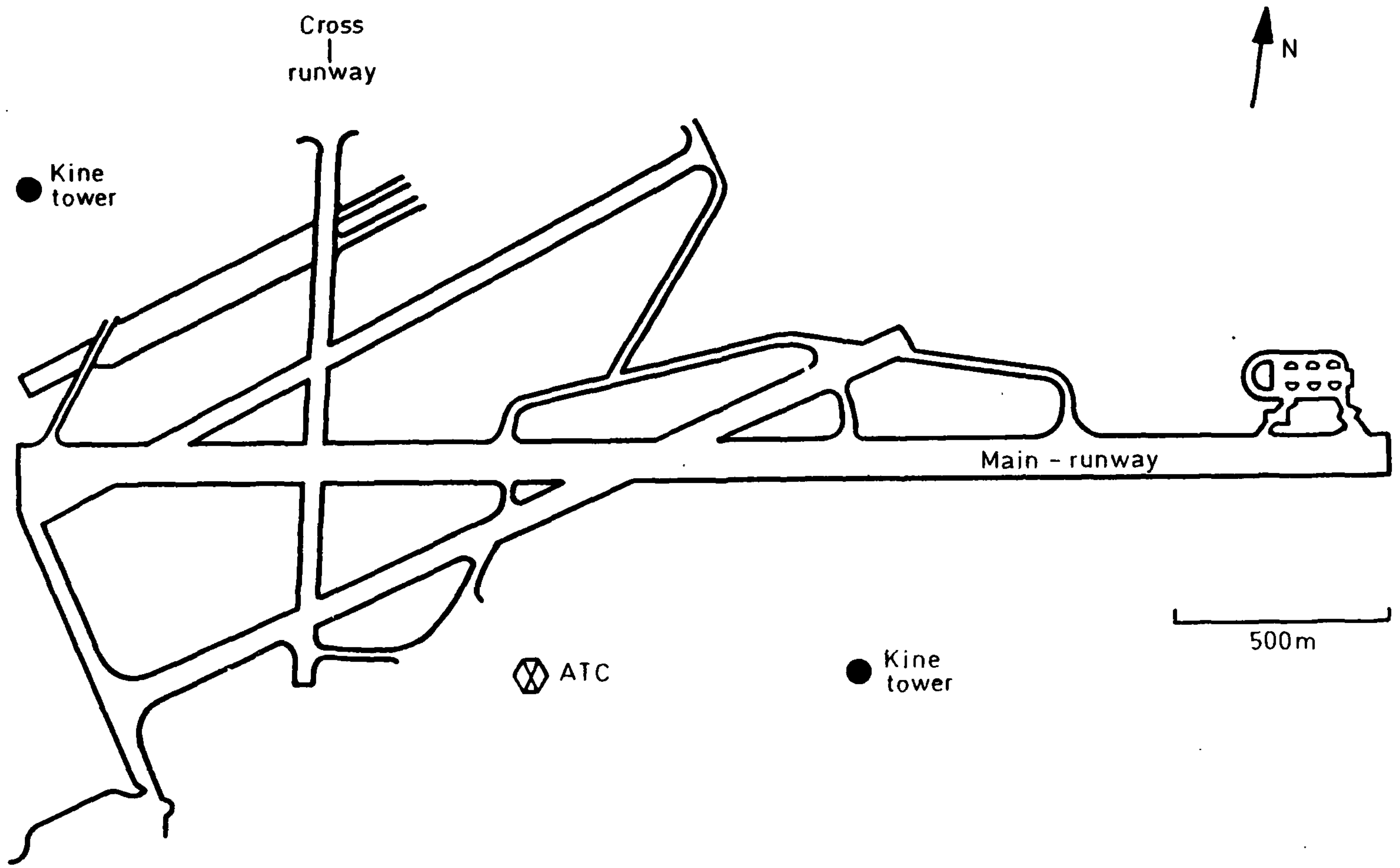

Fig 5a Runway layout at RAE Bedford

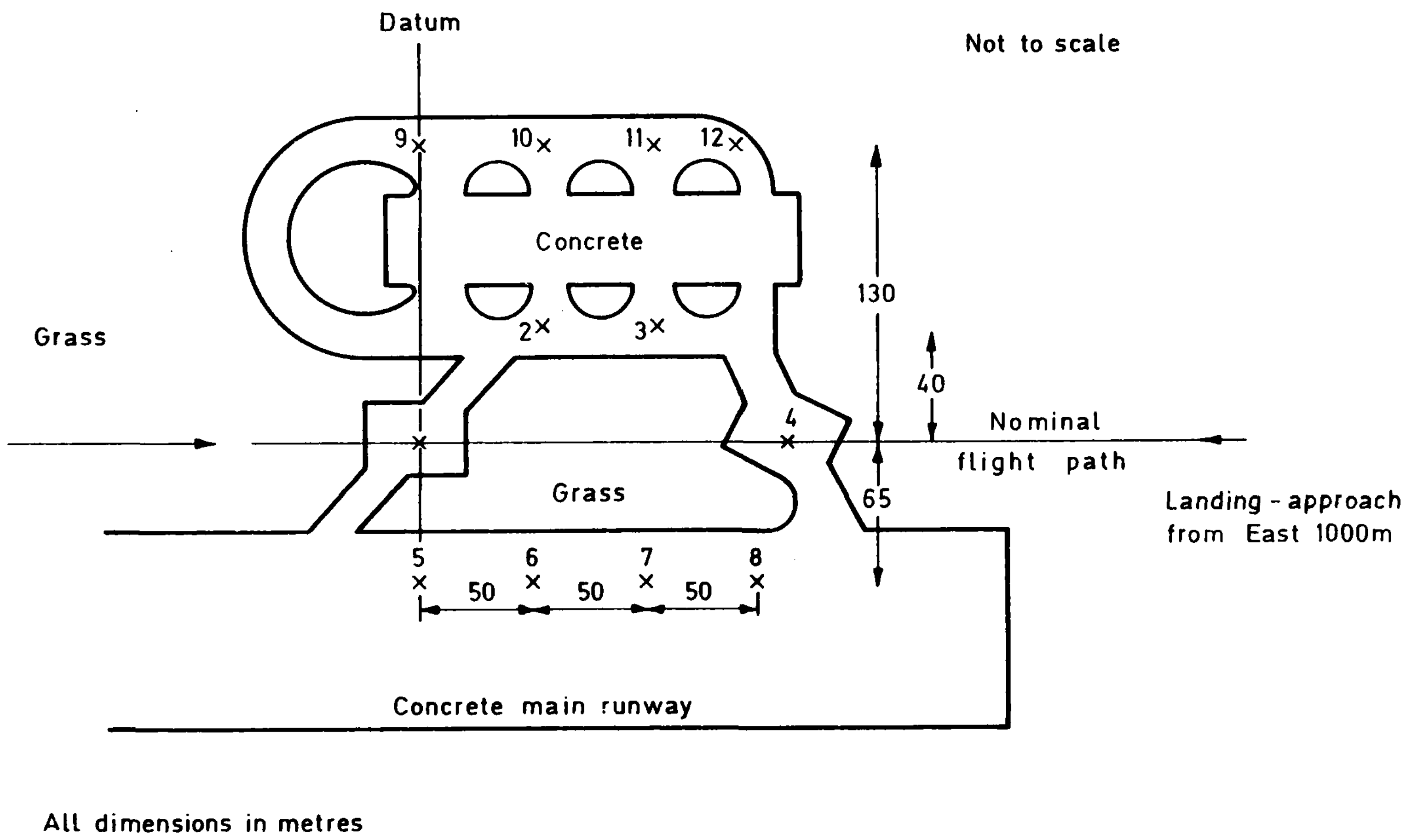

Fig 5b Microphone array and ground track (RAE Bedford)

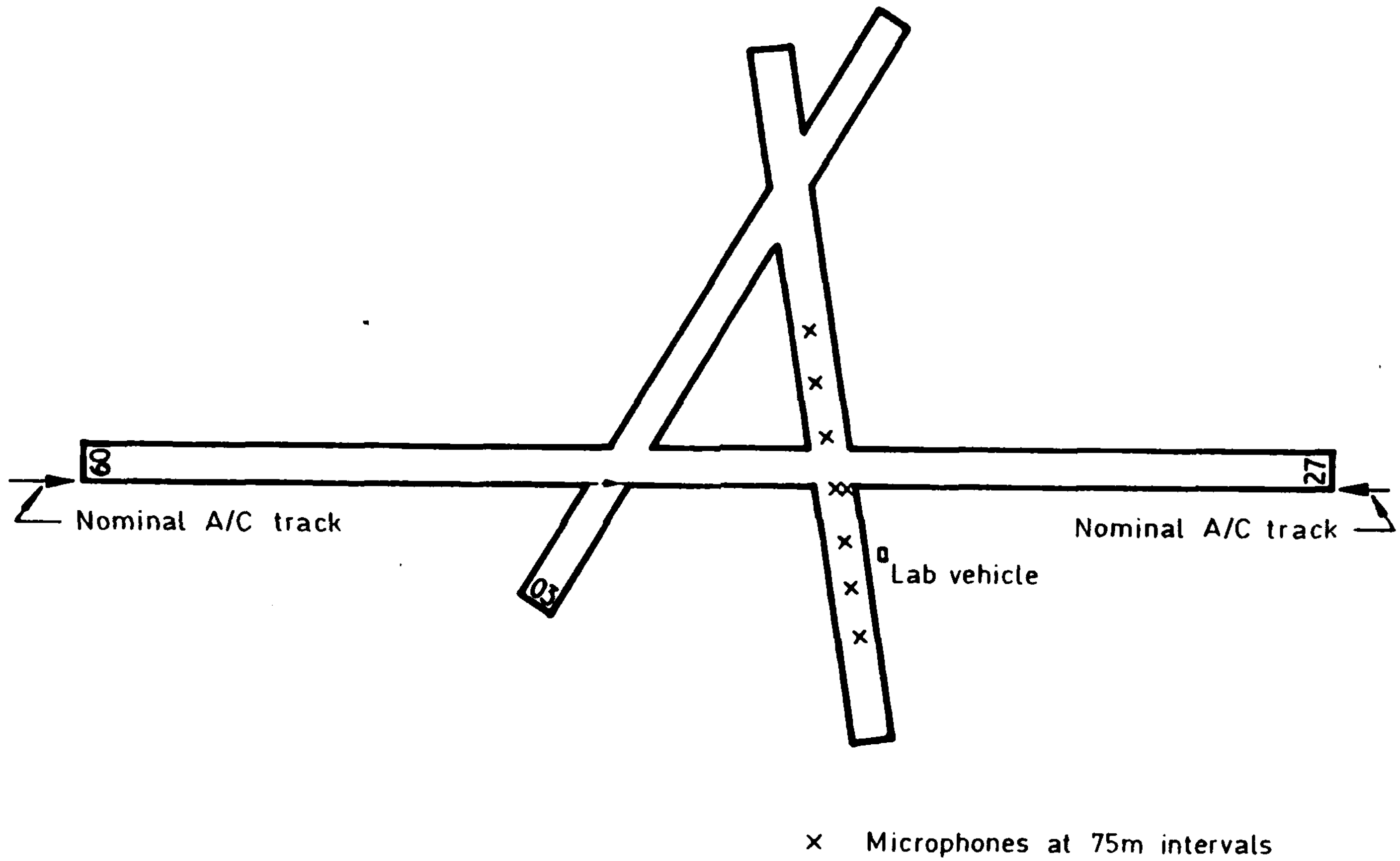

Fig 6 Plan of RNAS Merryfield showing microphone positions and a/c track

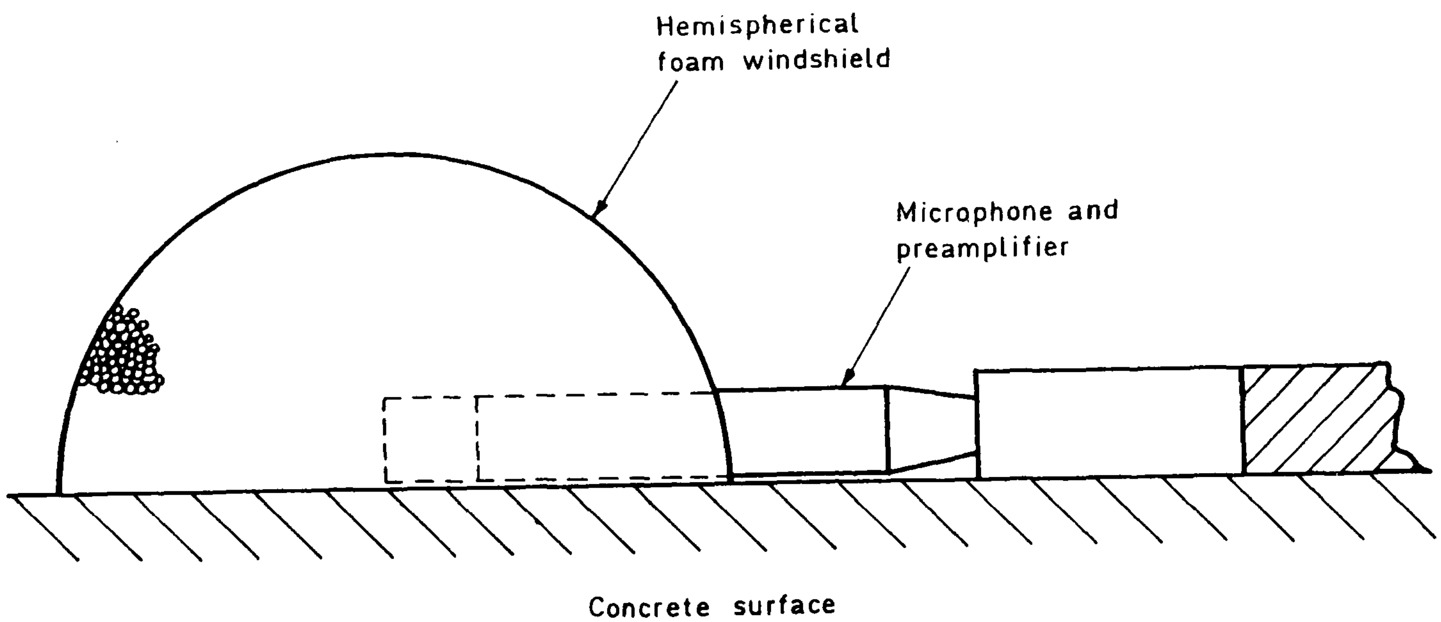

Fig 7 Ground mounting of microphone and windshield

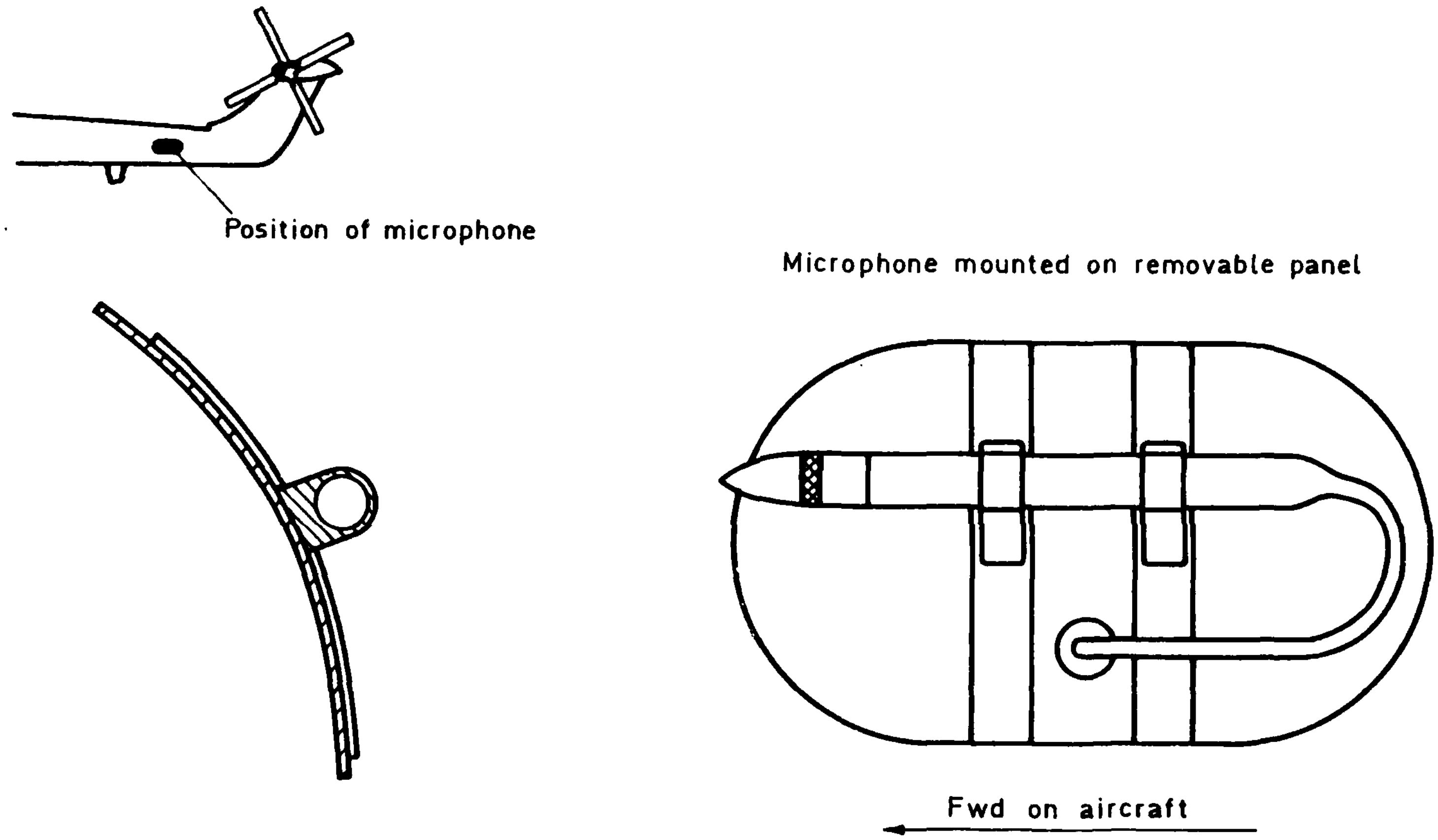

Fig 8 Position and mounting of tail-boom microphone

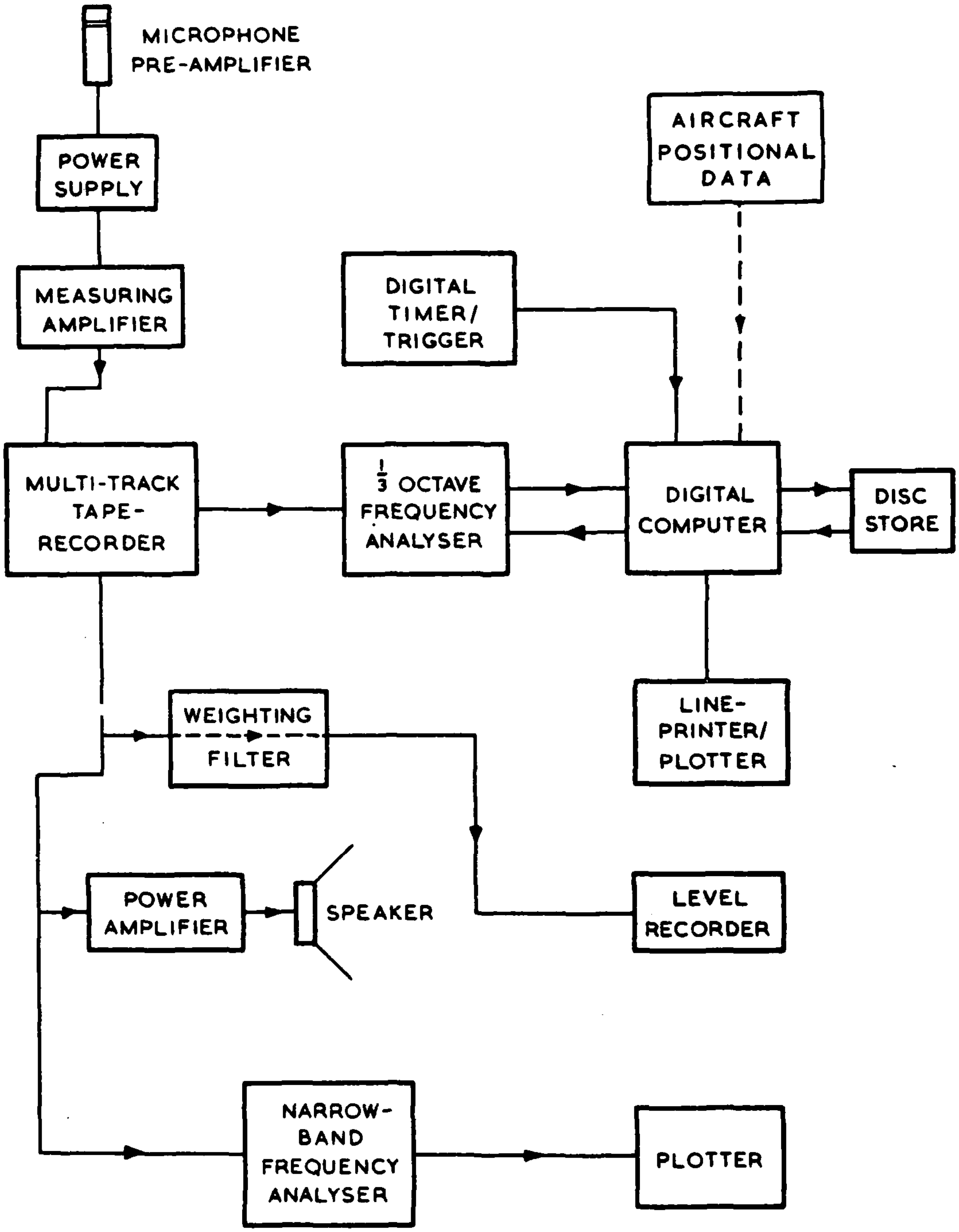

Fig 9 Recording/analysis system-helicopter flight trials

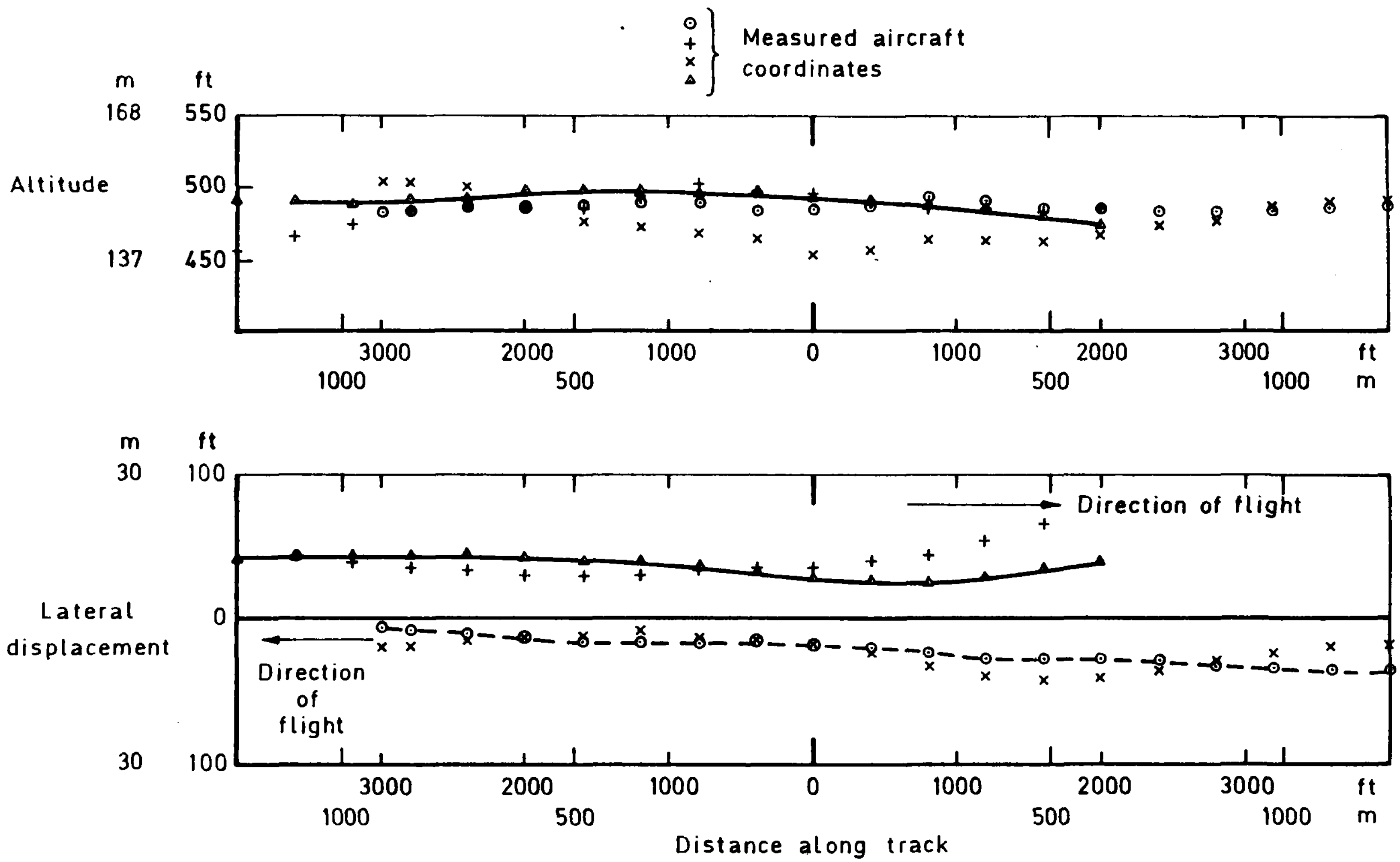

Fig 10 Aircraft path in level flight

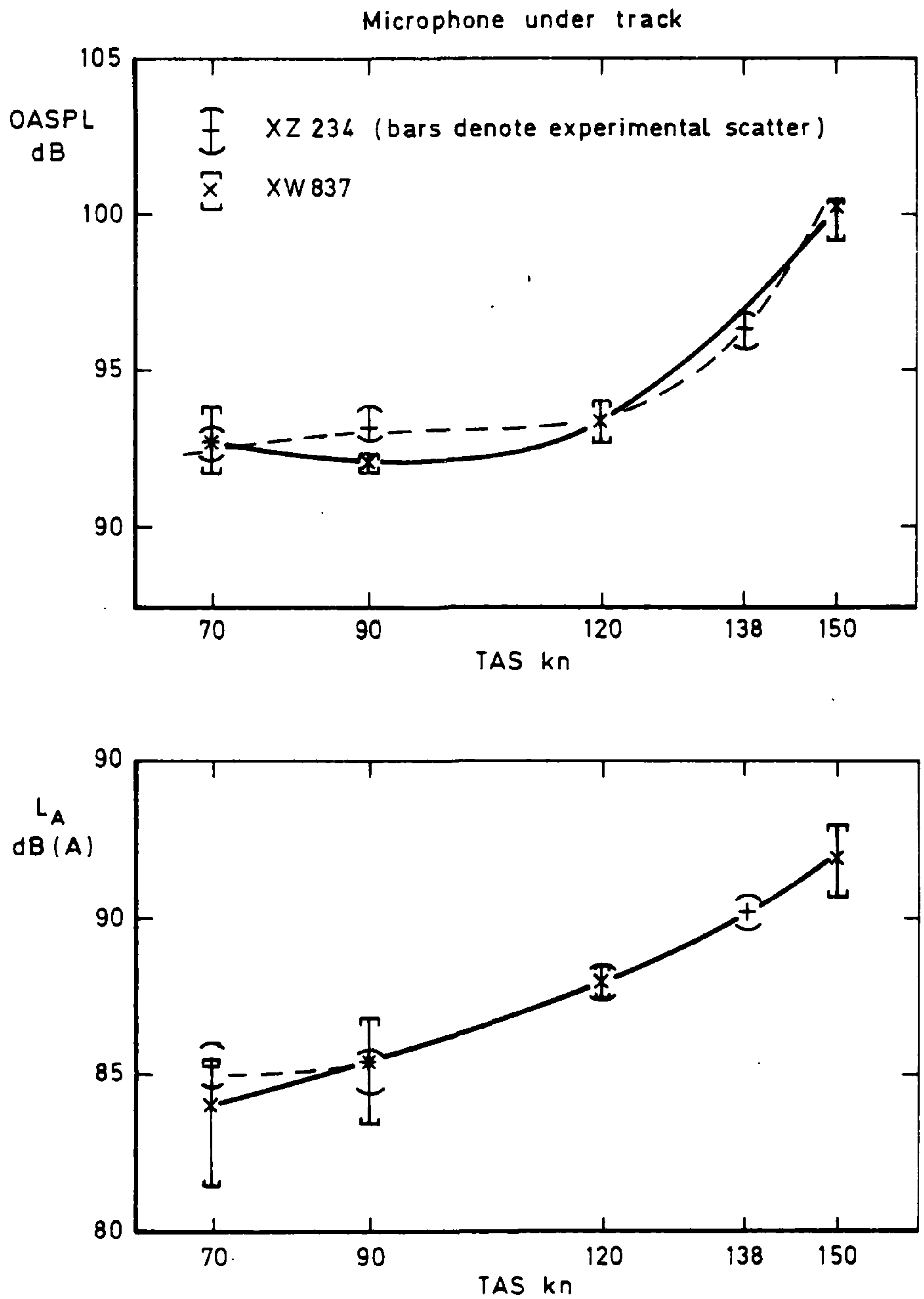

Fig 11a Effect of aircraft speed on OASPL and L_A

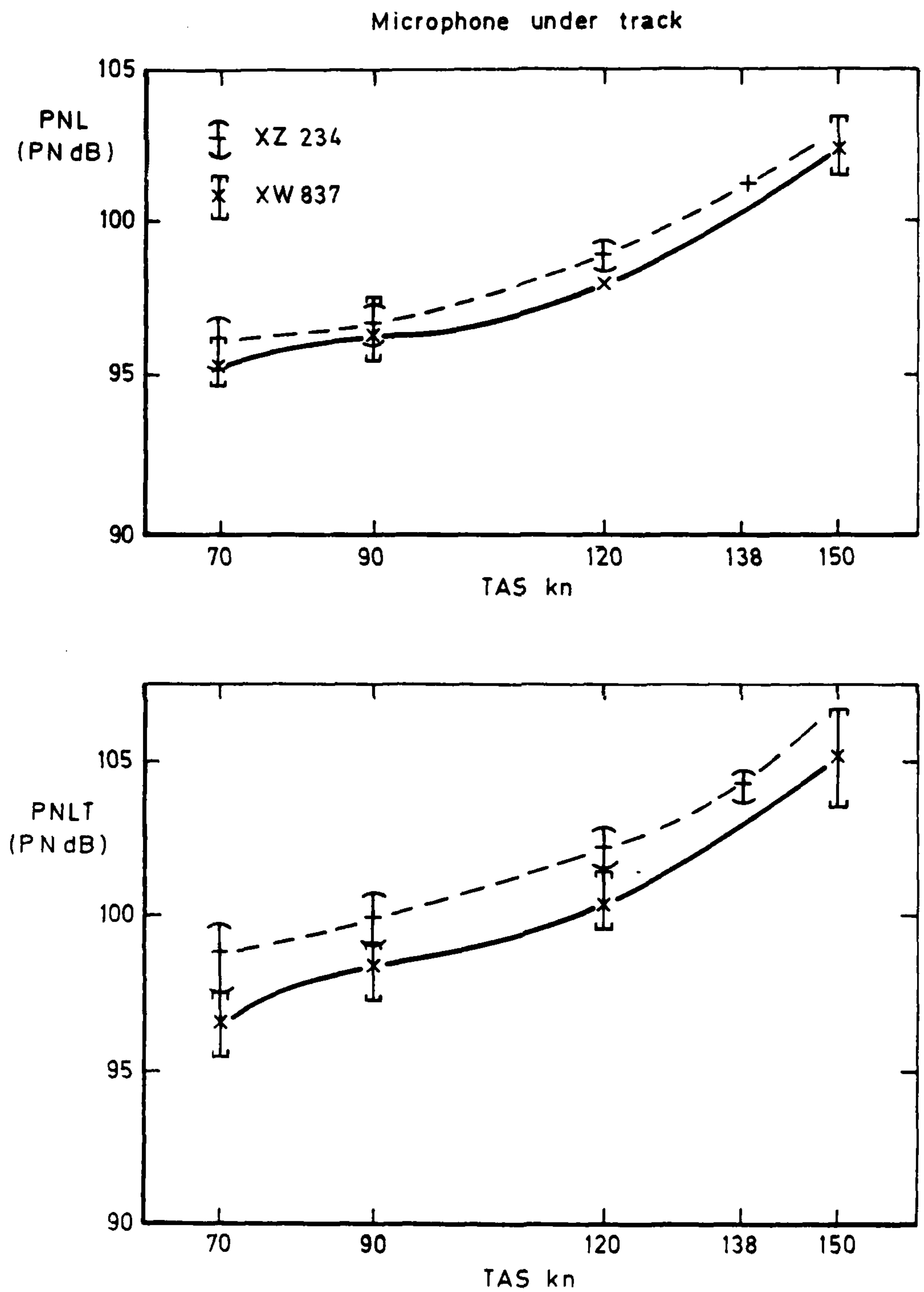

Fig 11b Effect of aircraft speed on PNL and PNLT

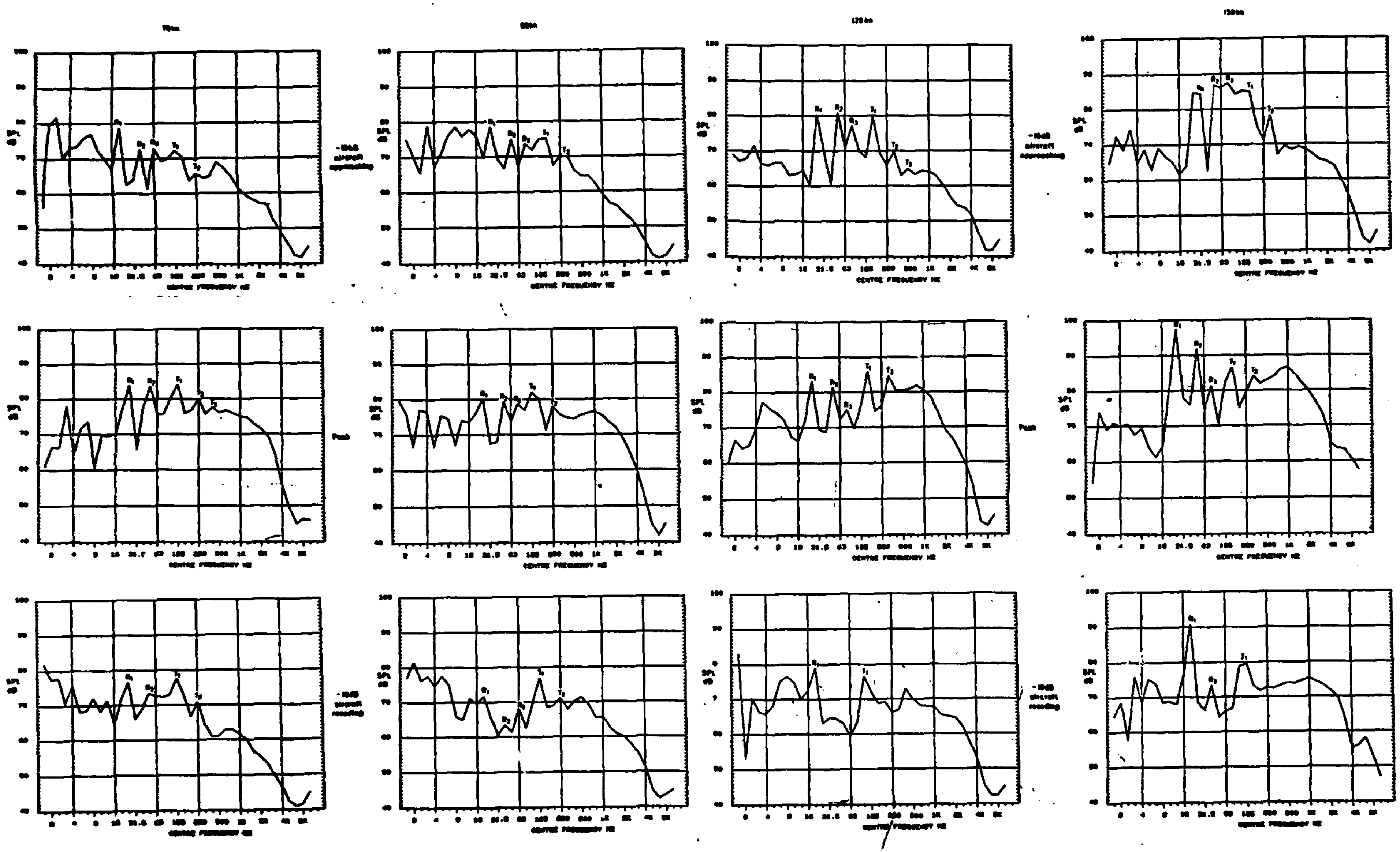

Fig 12 Effect of aircraft speed on 1/3-octave spectra (XW937)

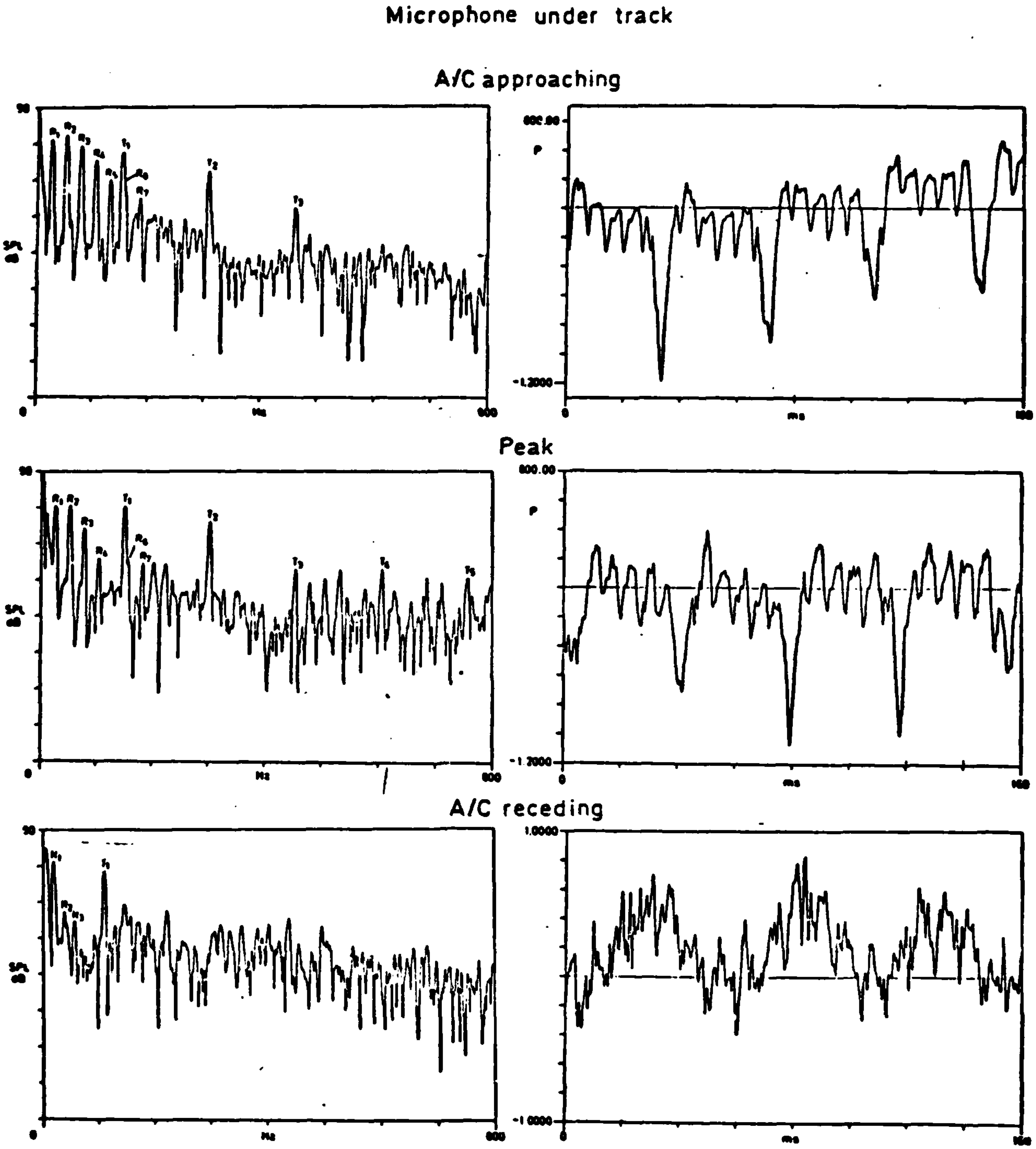

Fig 13 Typical narrow band spectra and pressure time history 120 kn at $PNLT_{max}$ and −10 dB points

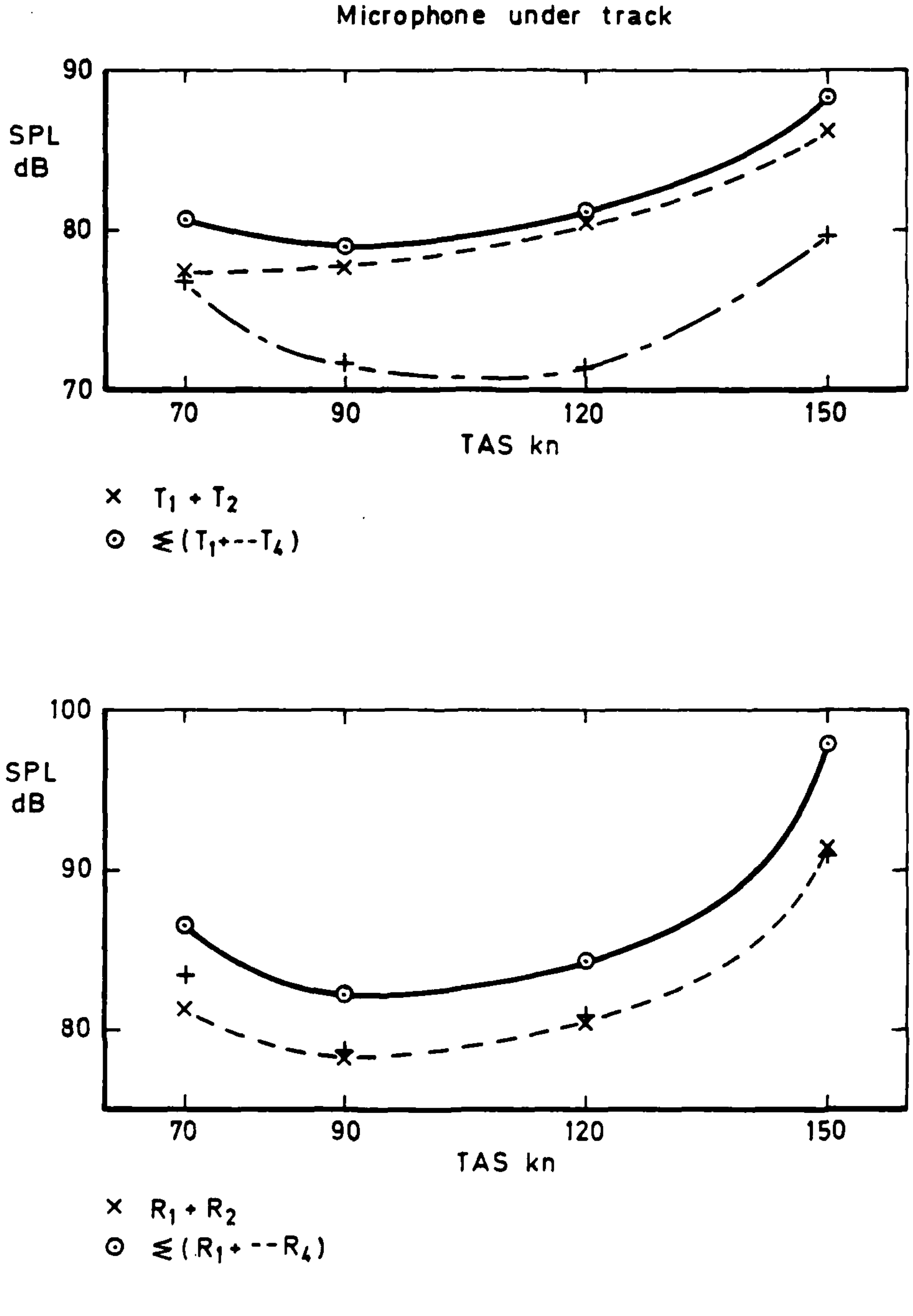

Fig 14 Rotor tone levels at $PNLT_{max}$ from ground microphone

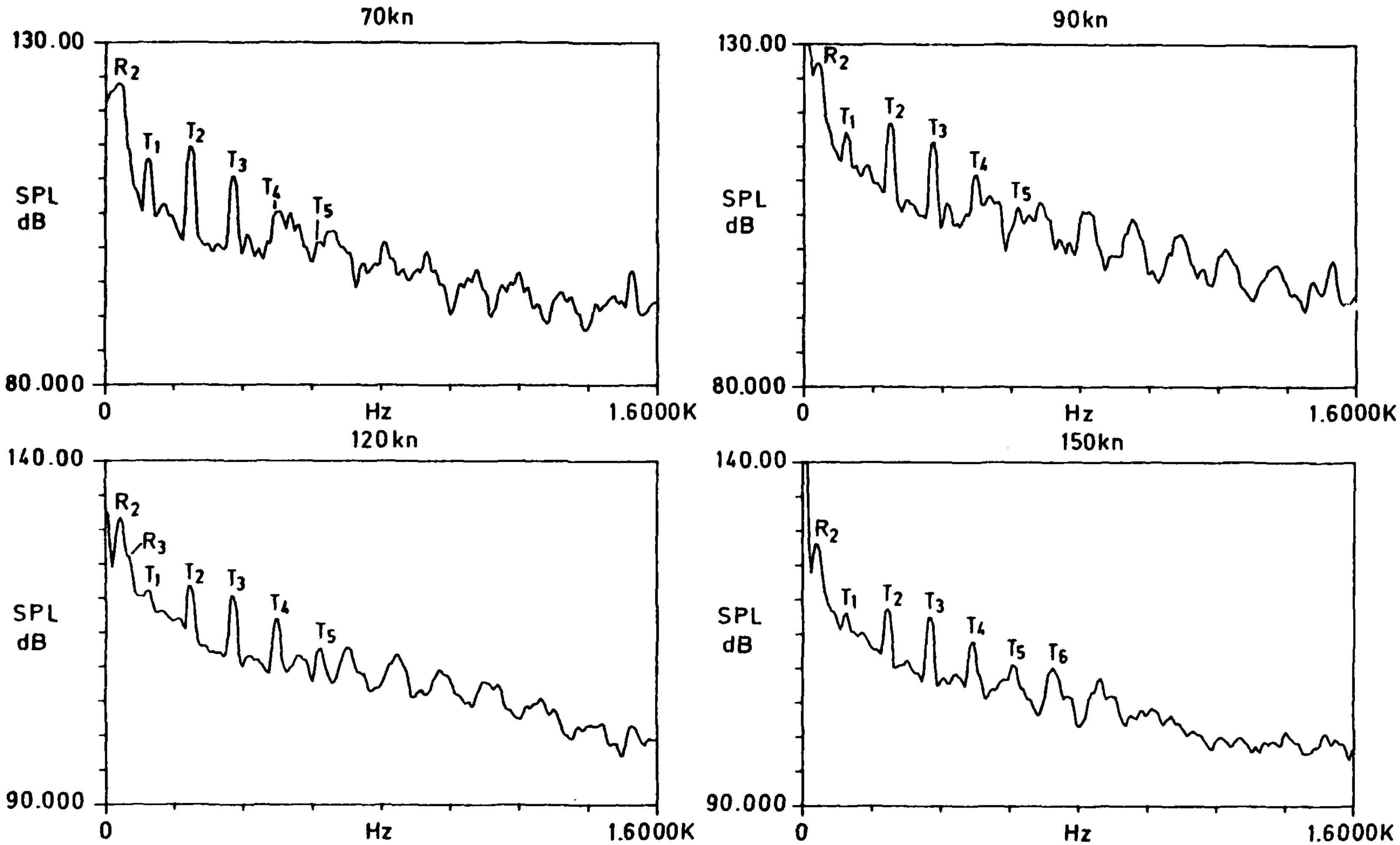

Fig 15a Narrow-band spectra from tail-boom microphone

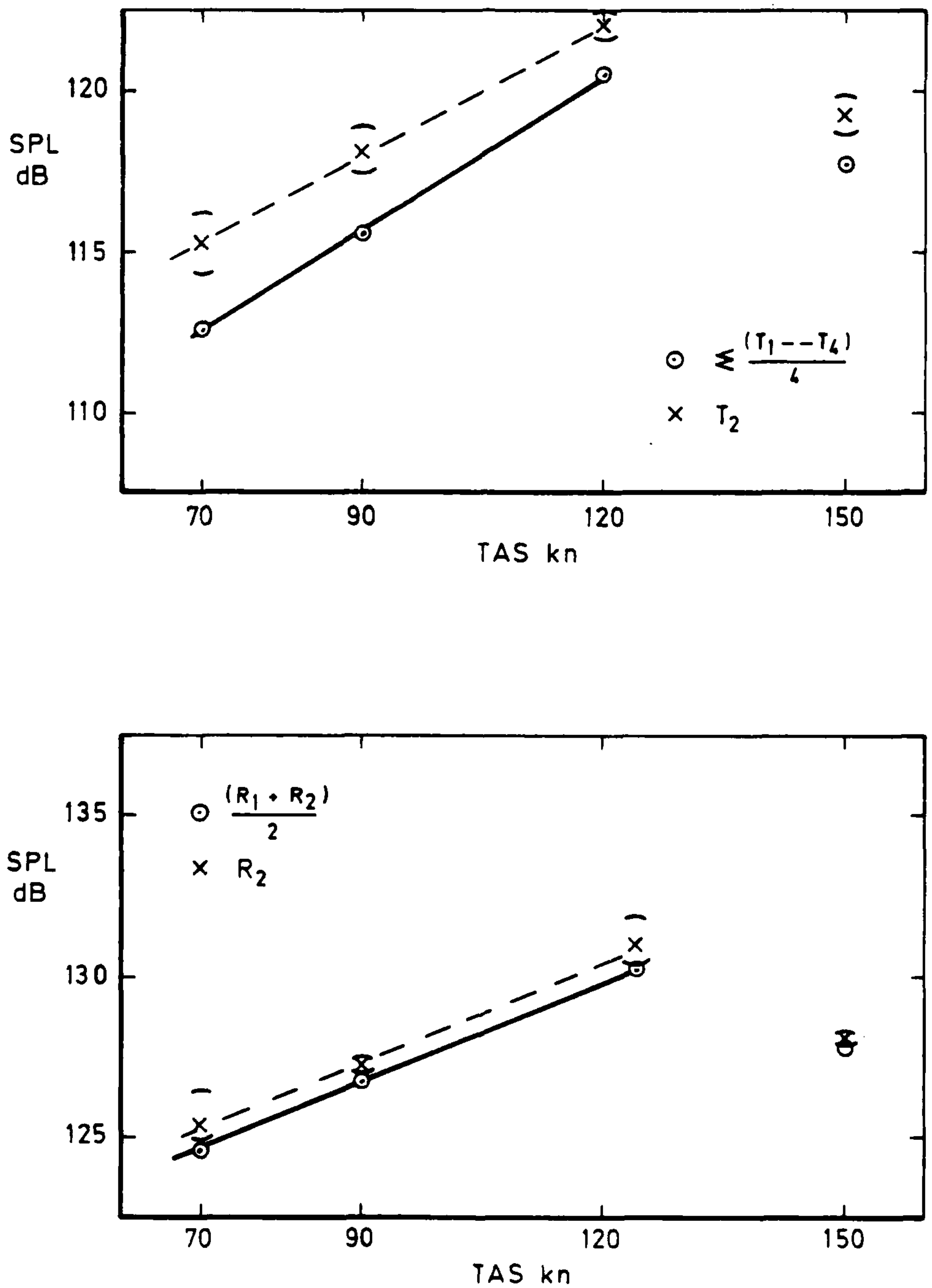

Fig 15b Rotor tone levels from tail-boom microphone

Fig 16a

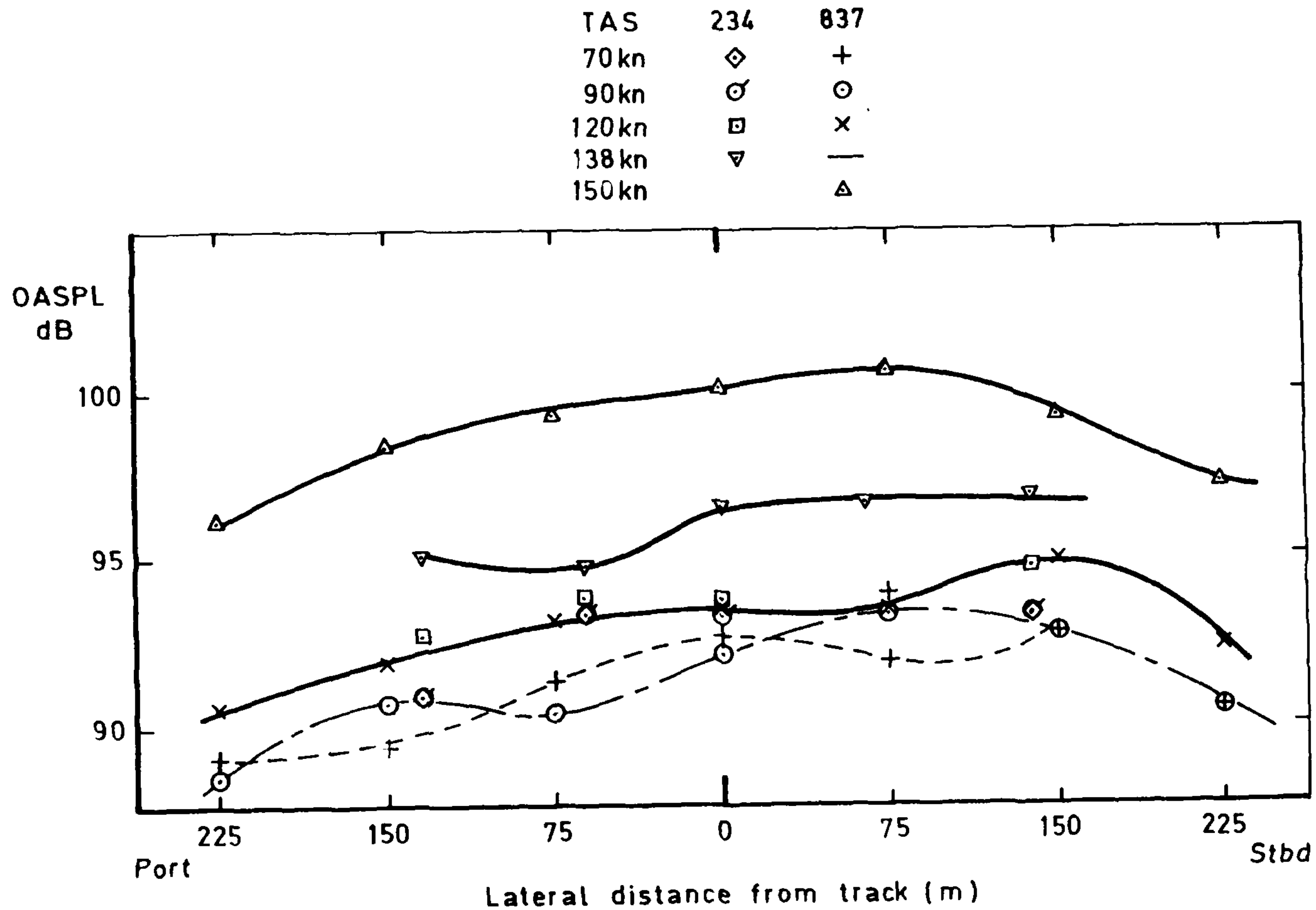

Fig 16a Lateral variation of overall sound pressure level with airspeed

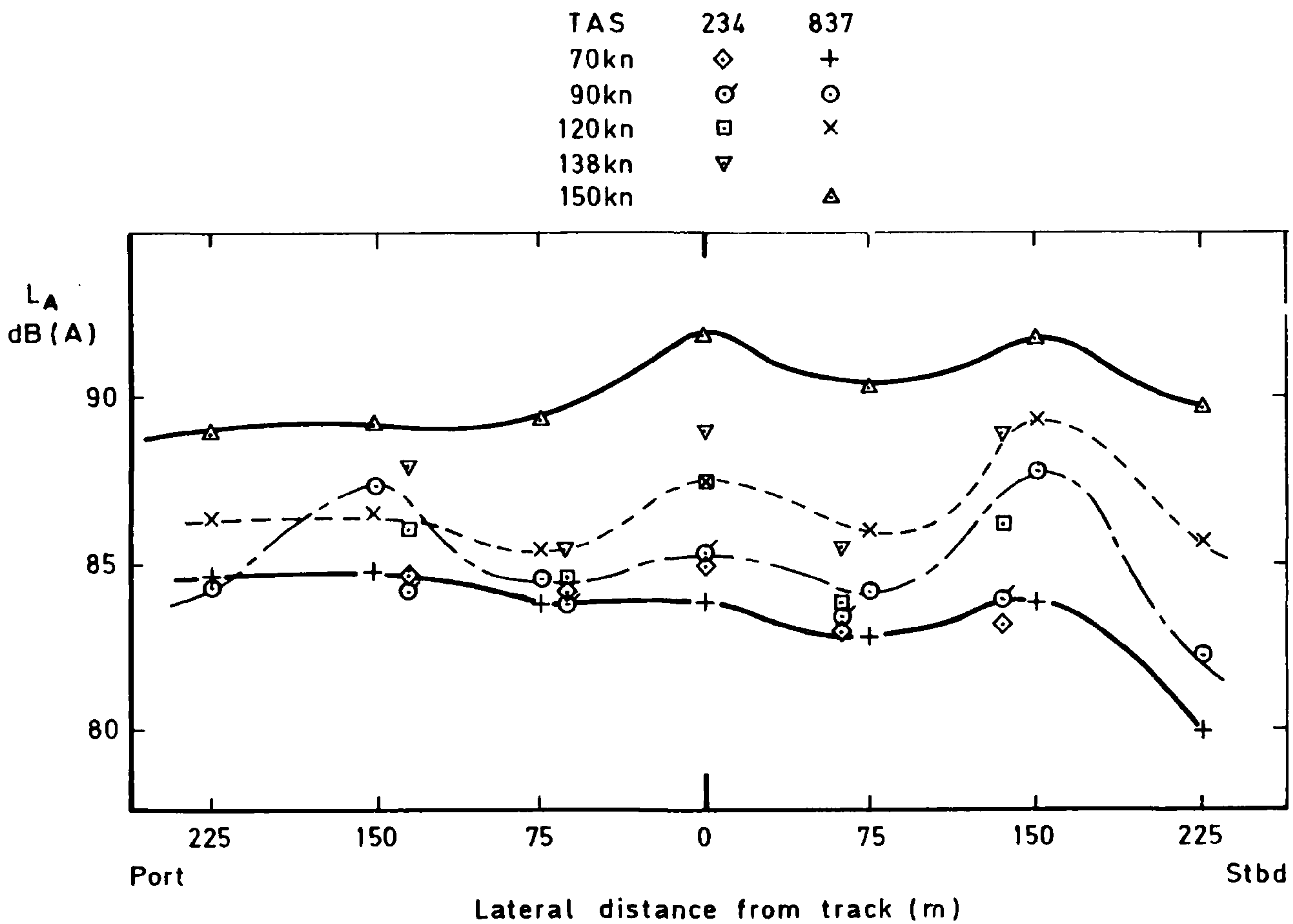

Fig 16b Lateral variation of a weighted overall sound pressure level with airspeed

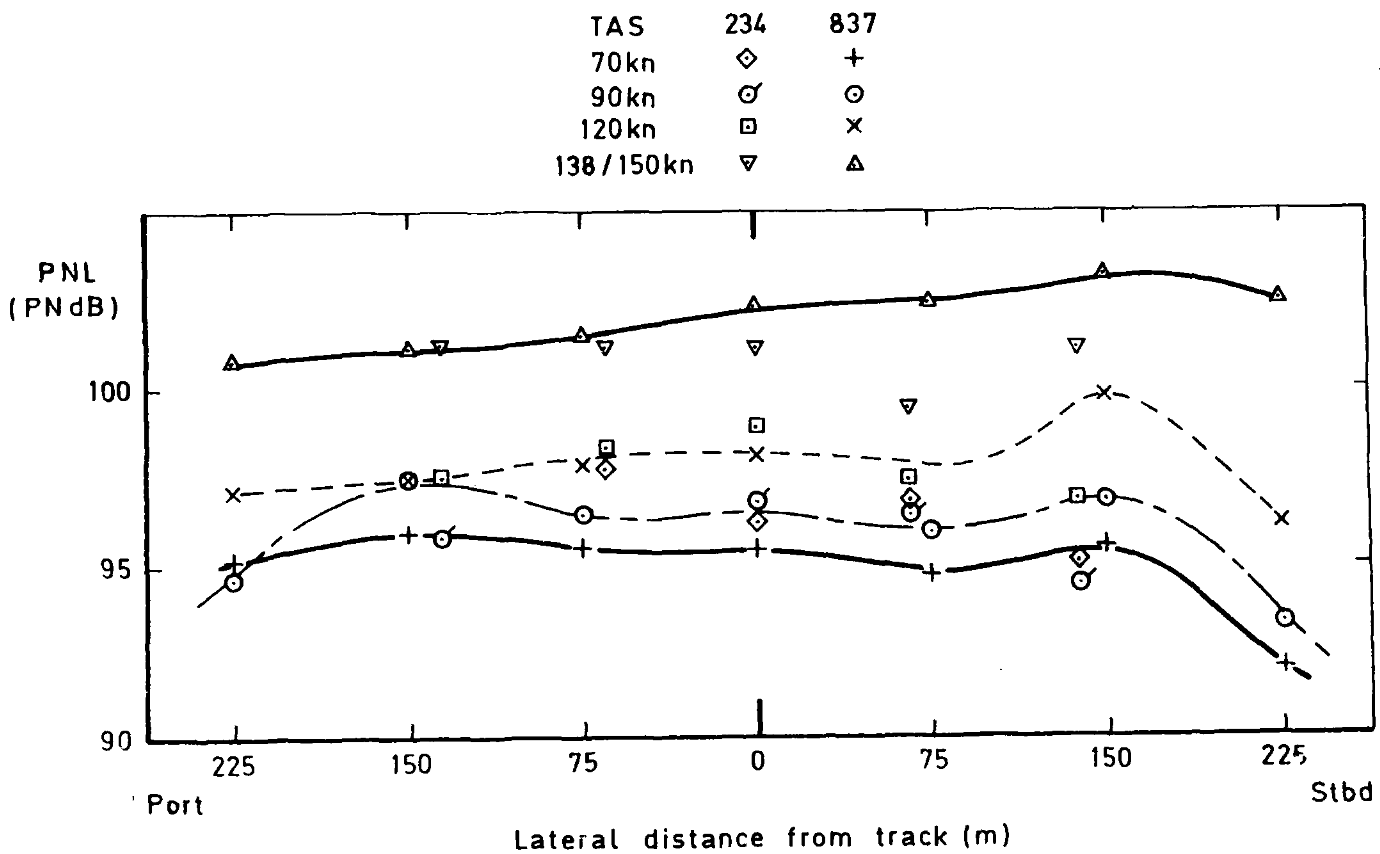

Fig 16c Lateral variation of perceived noise level with airspeed

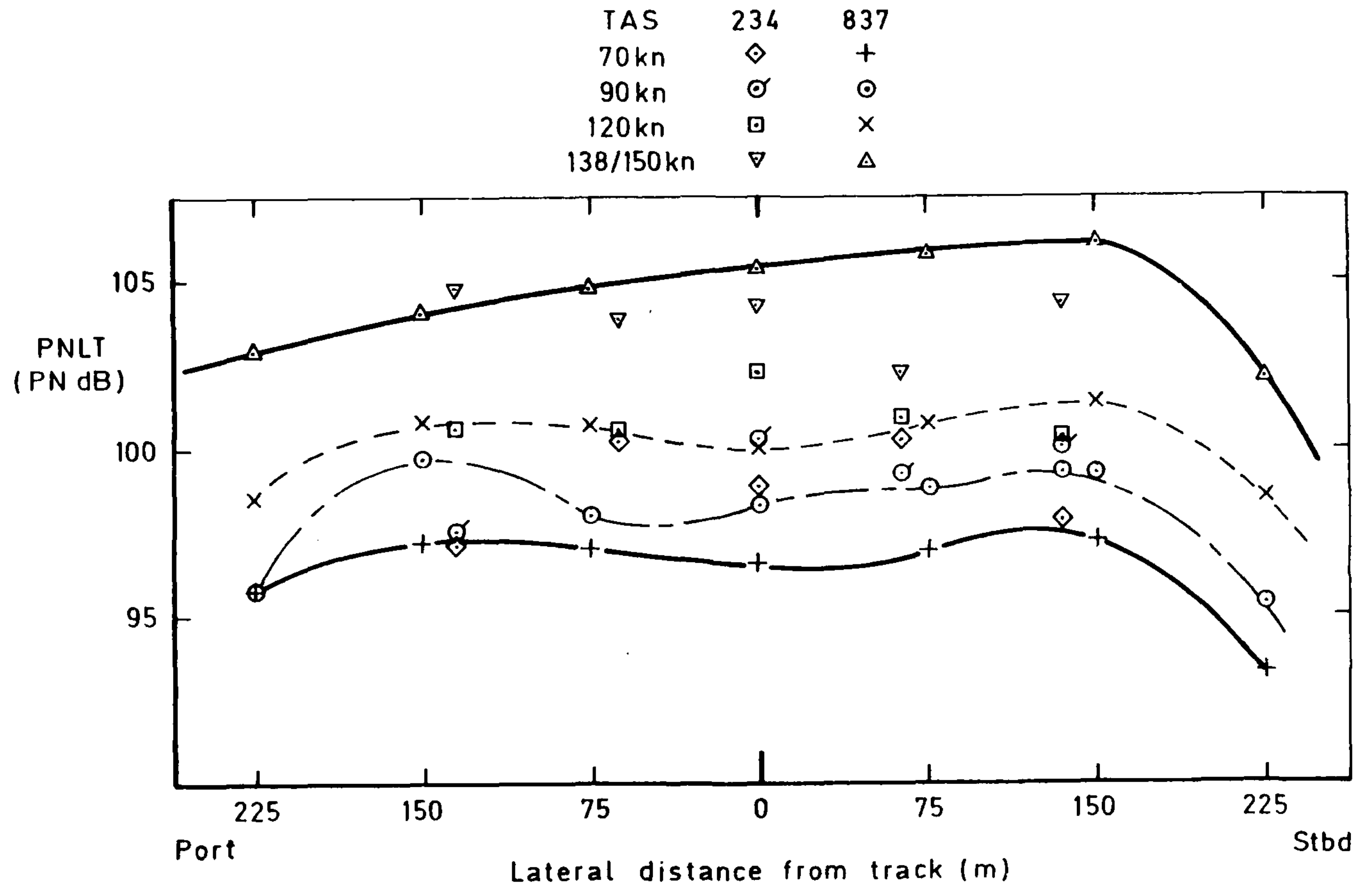

Fig 16d Lateral variation of tone corrected perceived noise level with airspeed

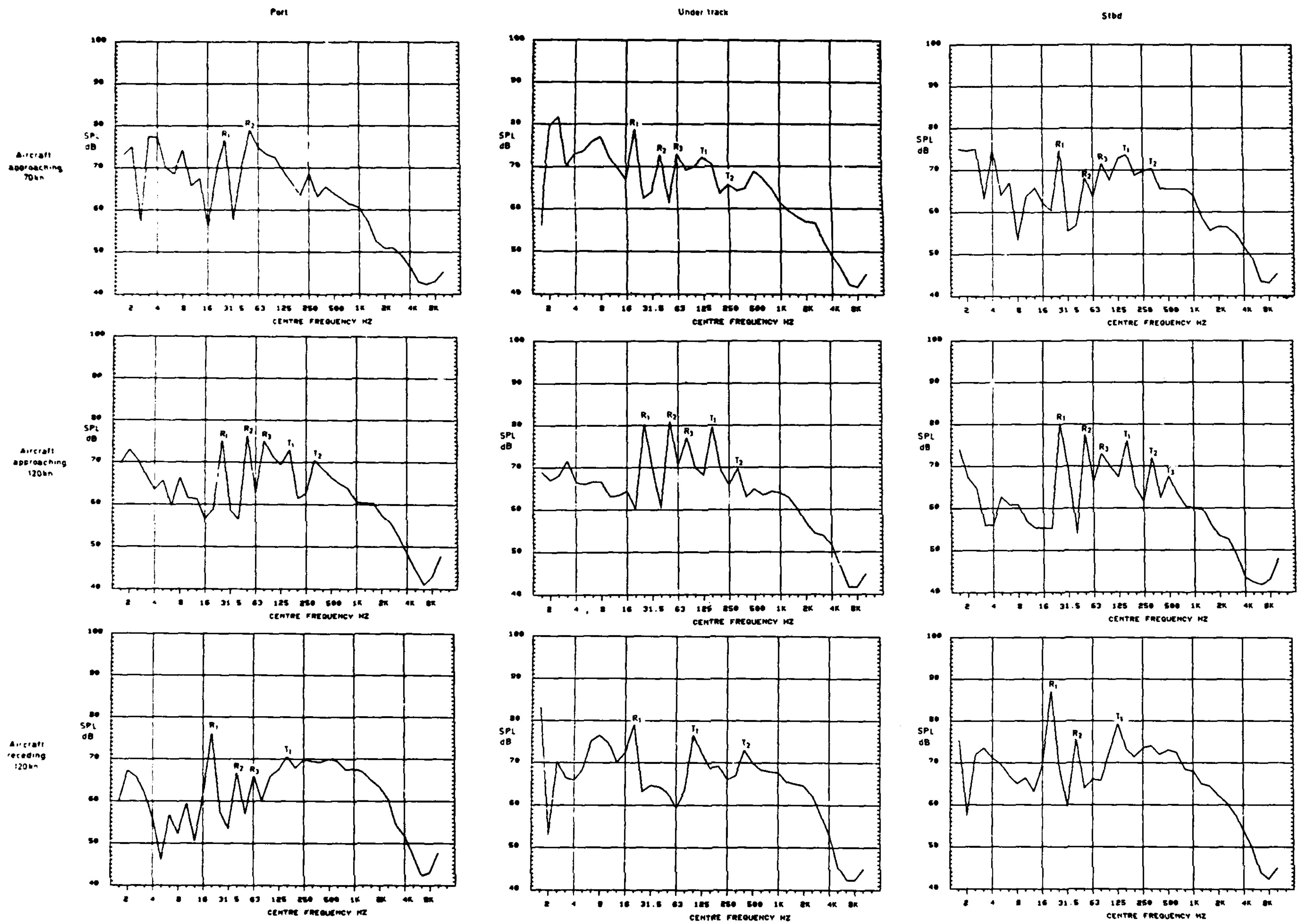

Fig 17 Effect of airspeed on 1/3-octave spectra before and after overhead

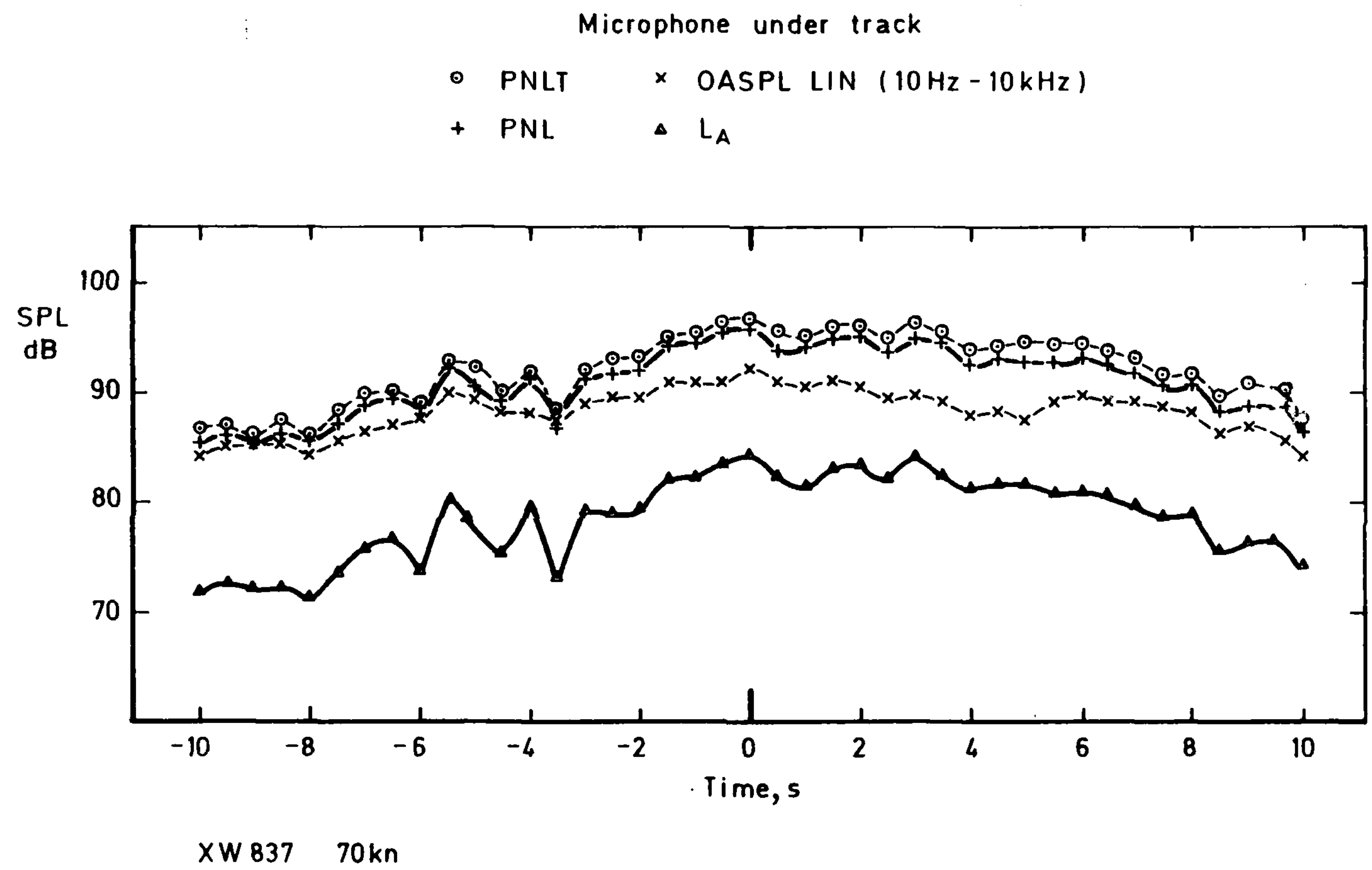

Fig 18a Variation in noise levels with time

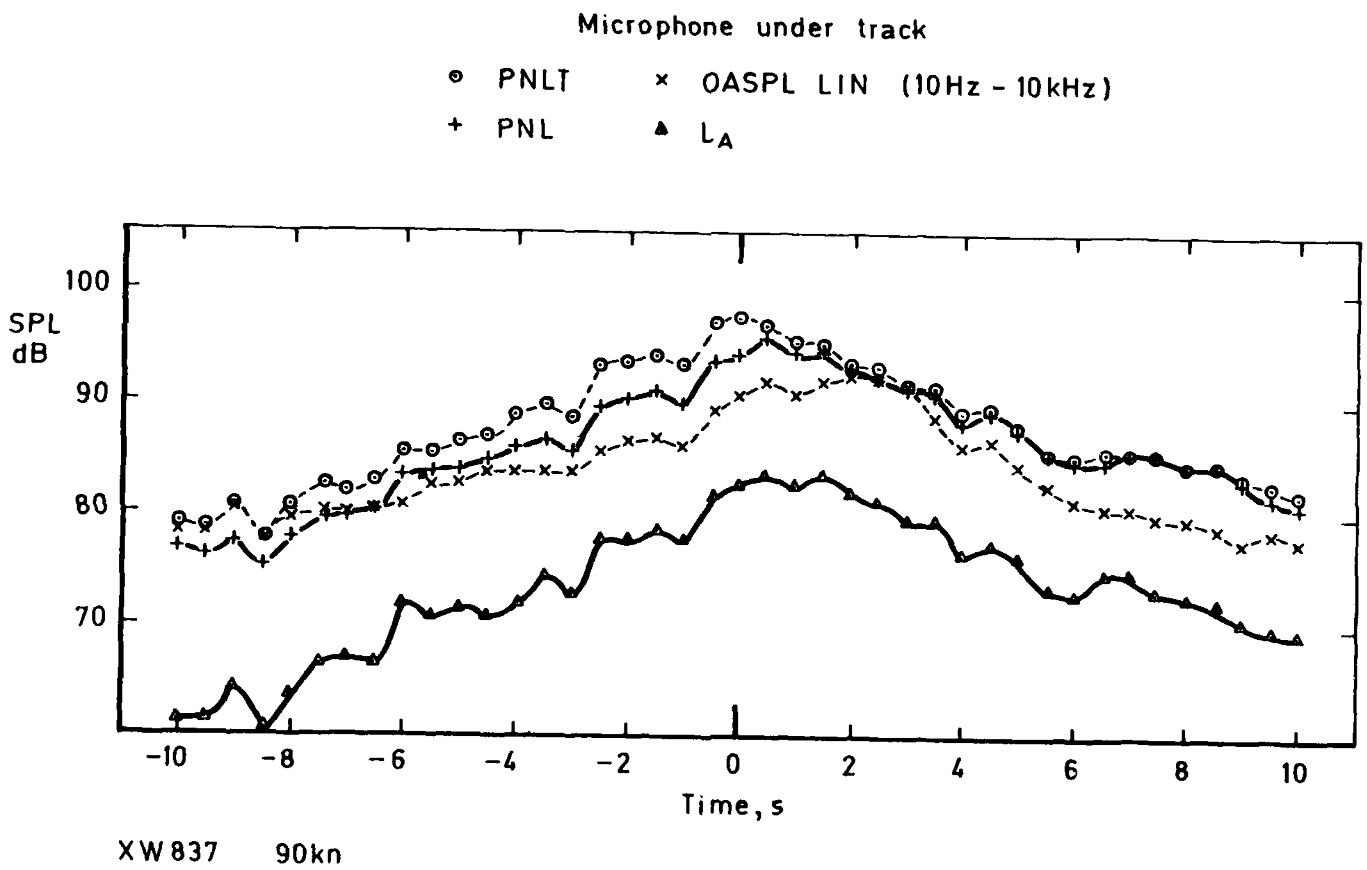

Fig 18b Variation in noise levels with time

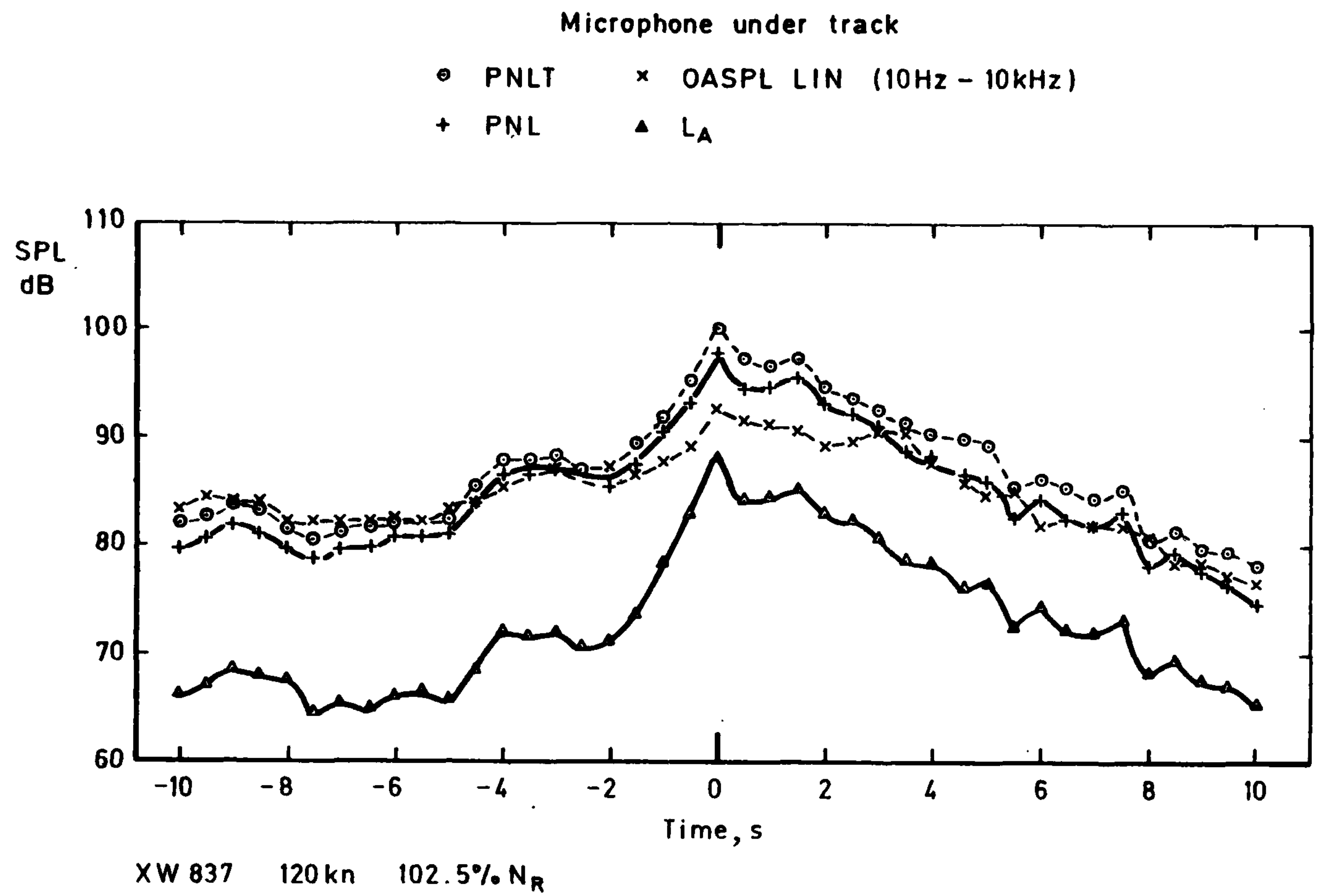

Fig 18c Variation in noise levels with time

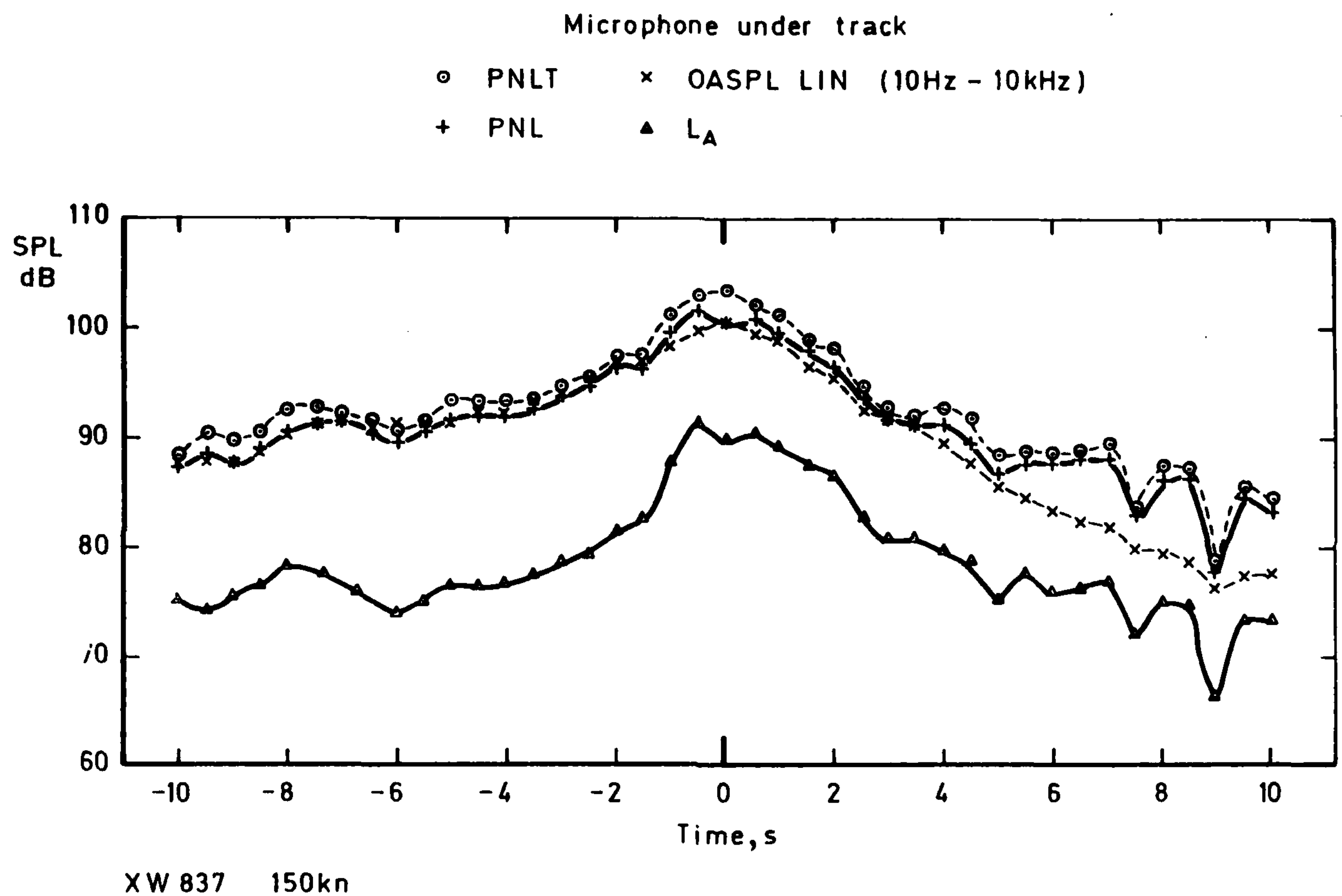

Fig 18d Variation in noise levels with time

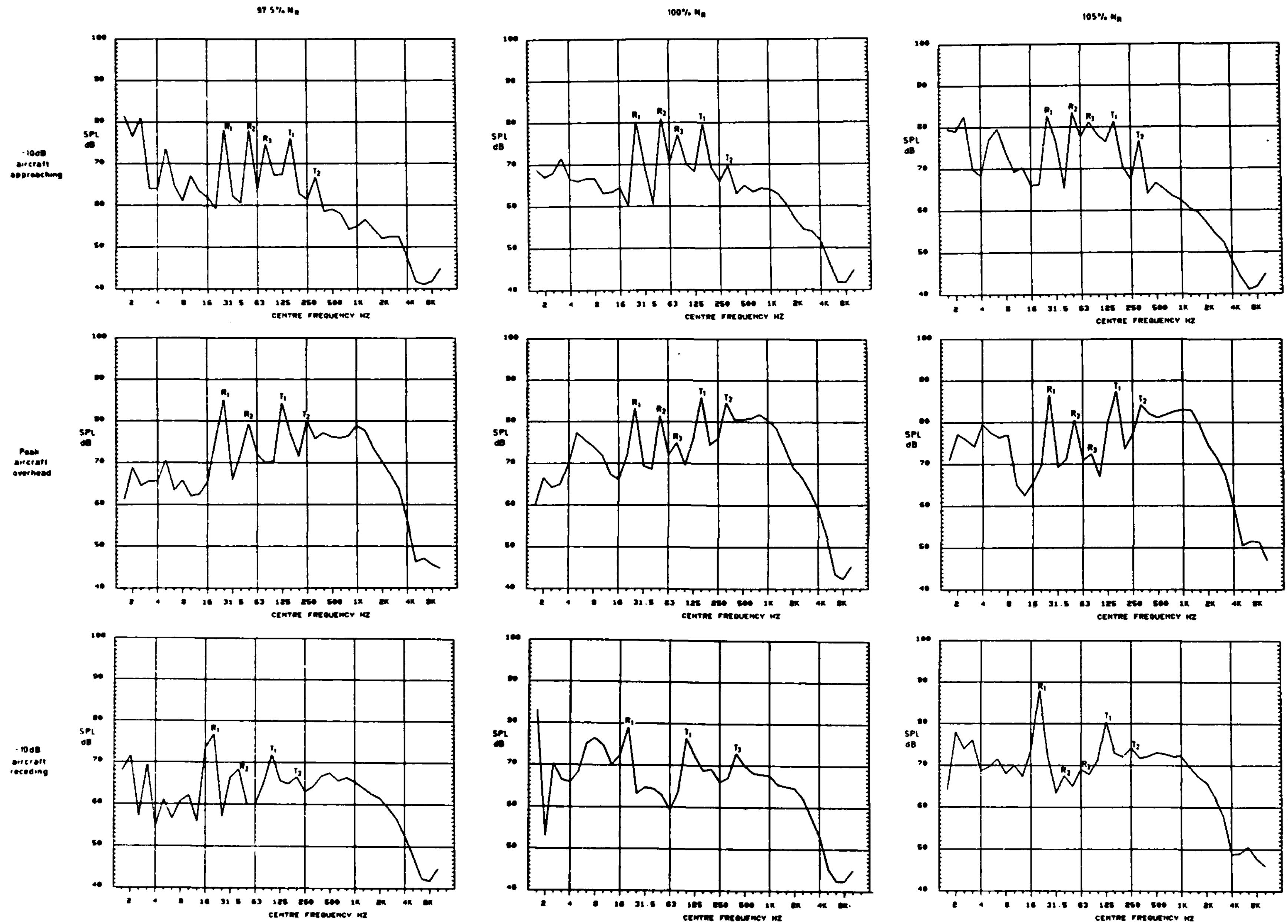

Fig 19a Effect of rotor rotational speed on 1/3-octave spectra (XW837)

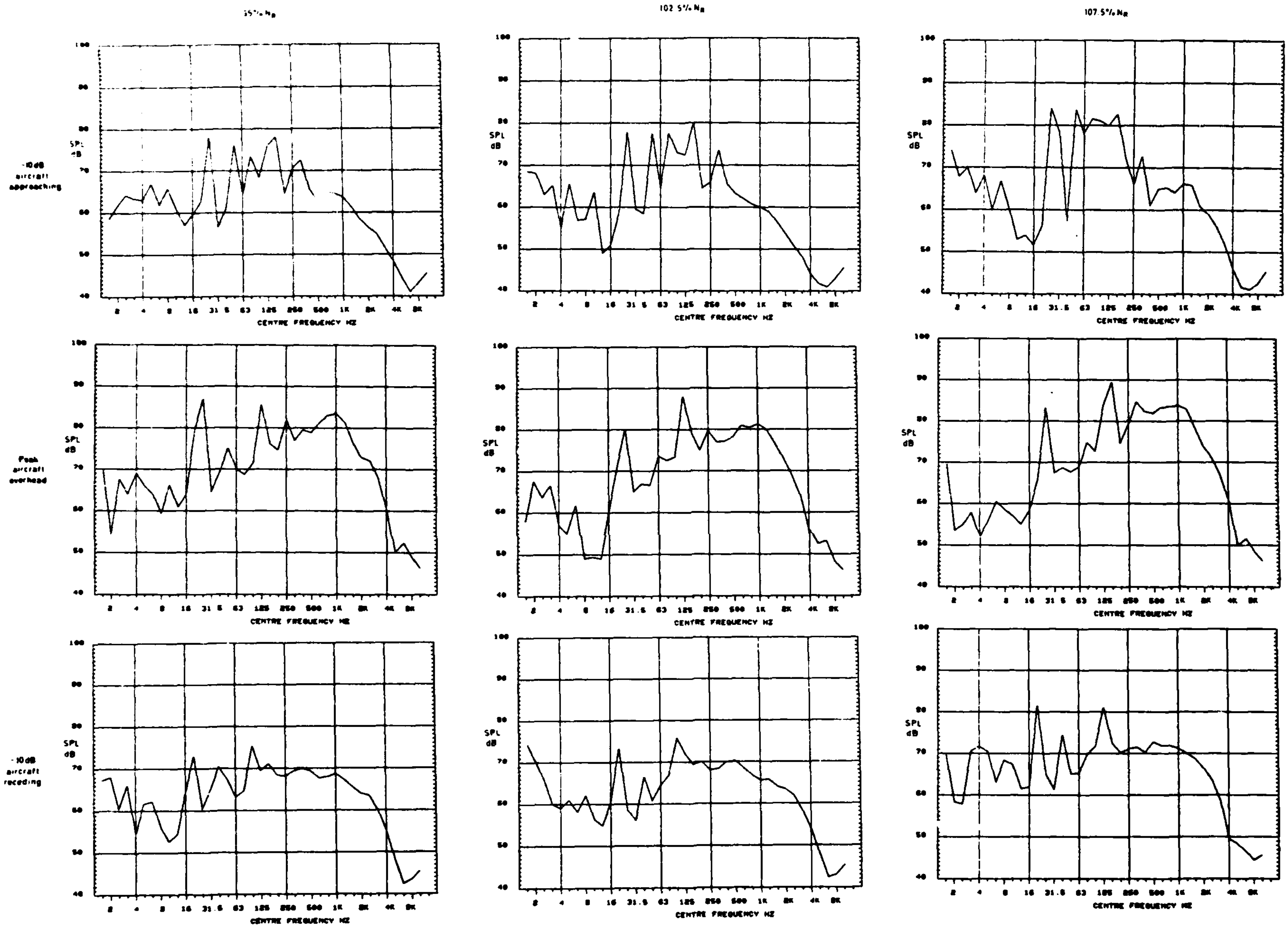

Fig 19b Effect of rotor rotational speed on 1/3-octave spectra (XX910)

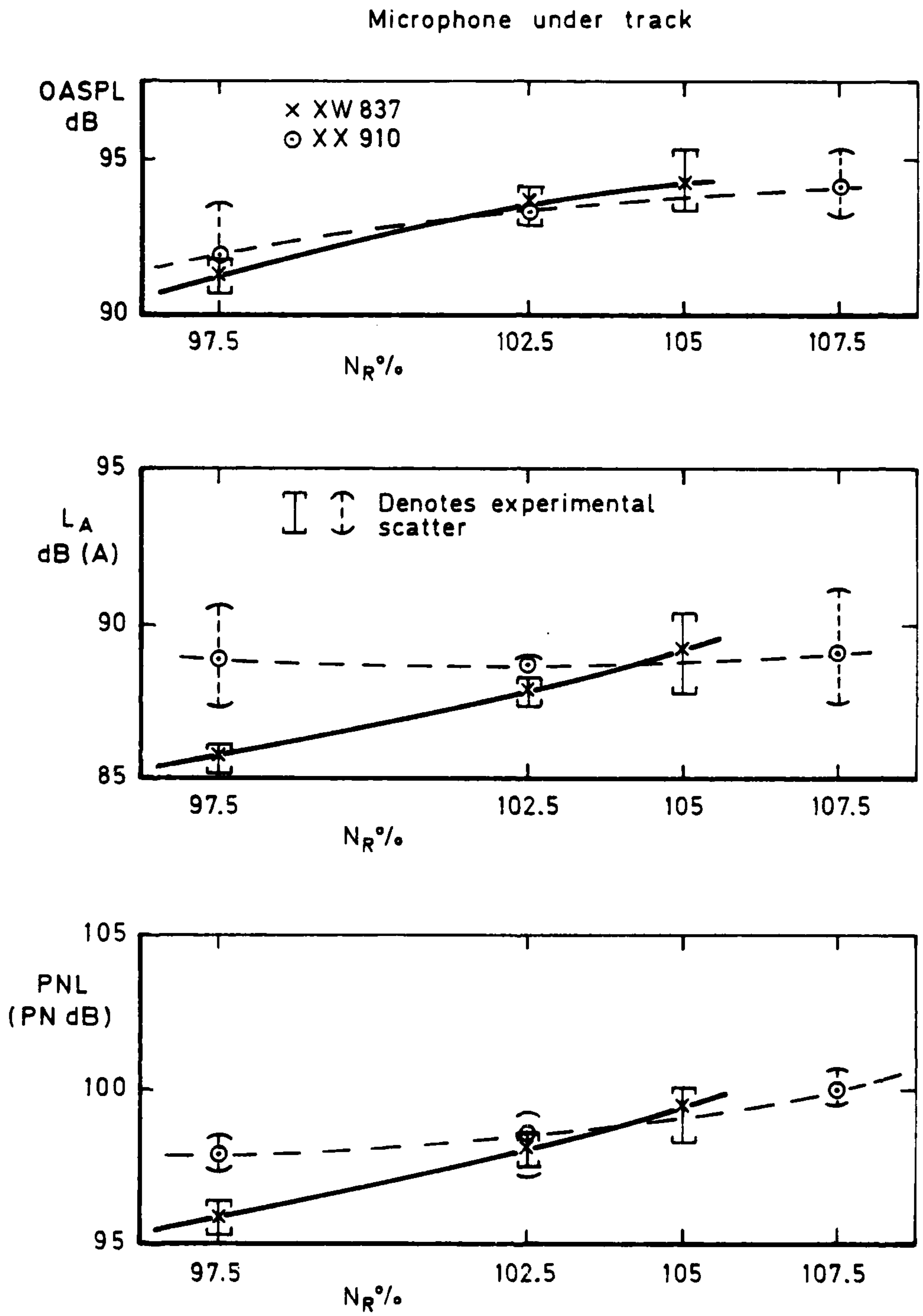

Fig 20 Effect of rotor rotational speed on noise levels

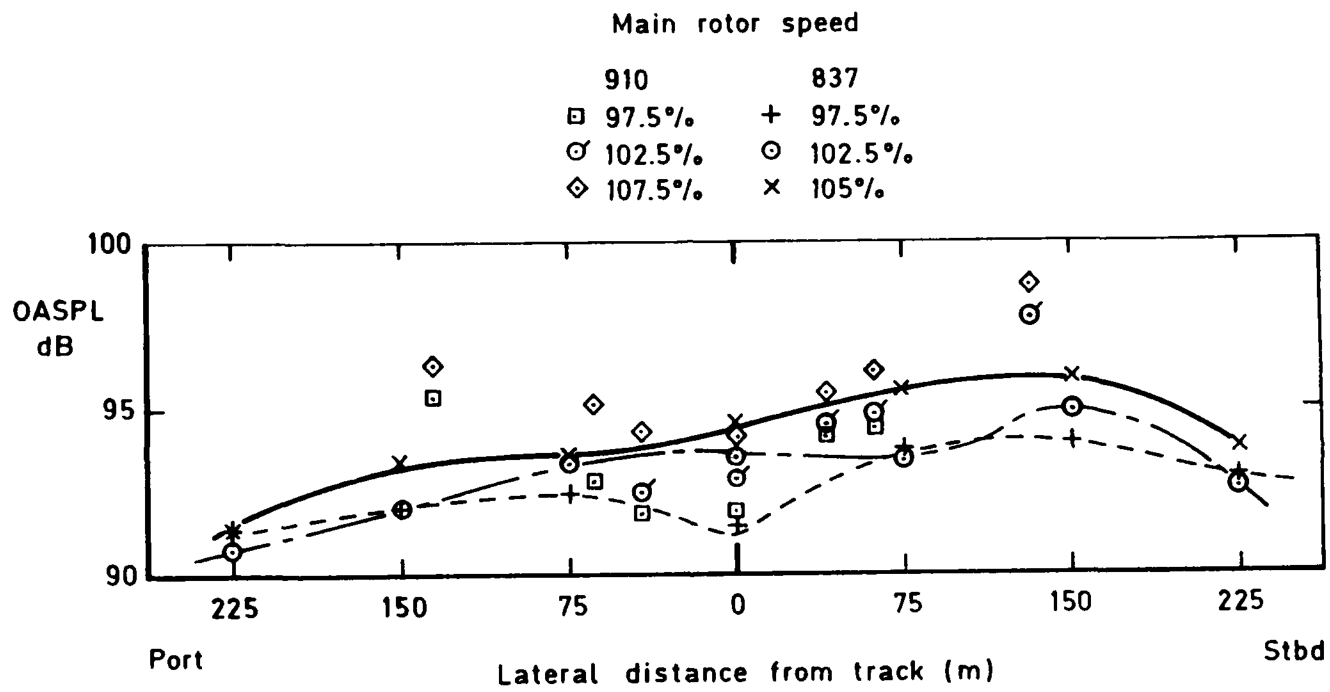

Fig 21a Lateral variation of overall sound pressure level with rotor rotational speed

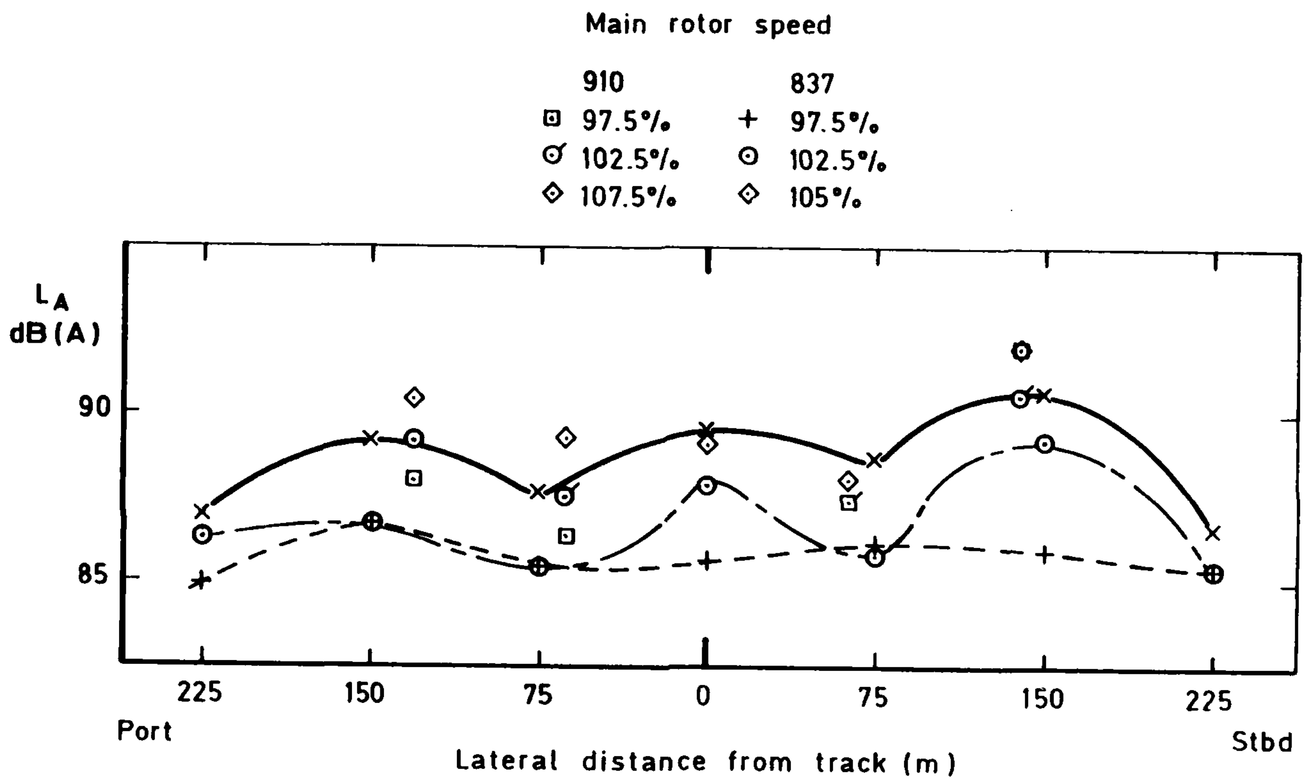

Fig 21b Lateral variation of a weighted overall sound pressure level with rotor rotational speed

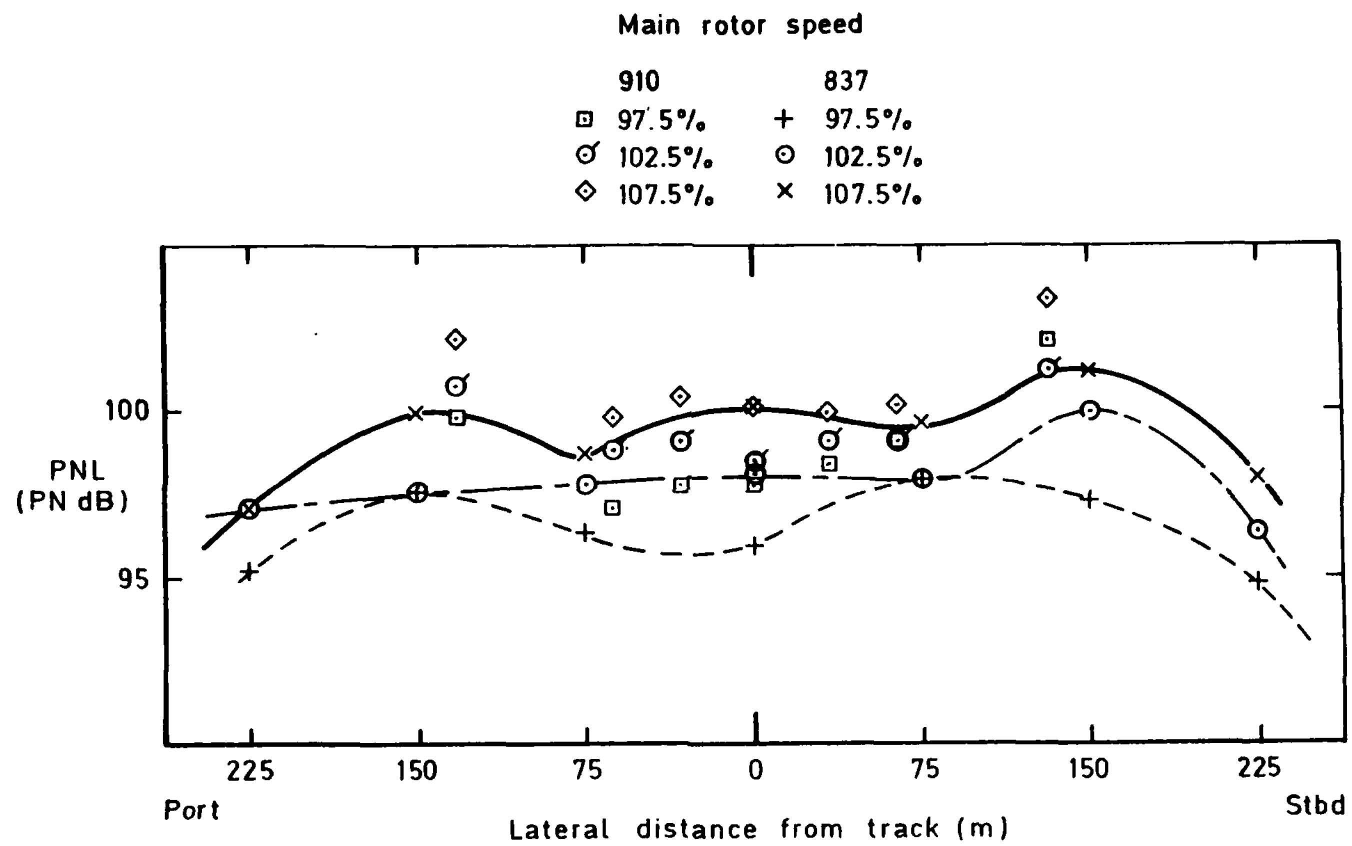

Fig 21c **Lateral variation of perceived noise level with rotor rotational speed**

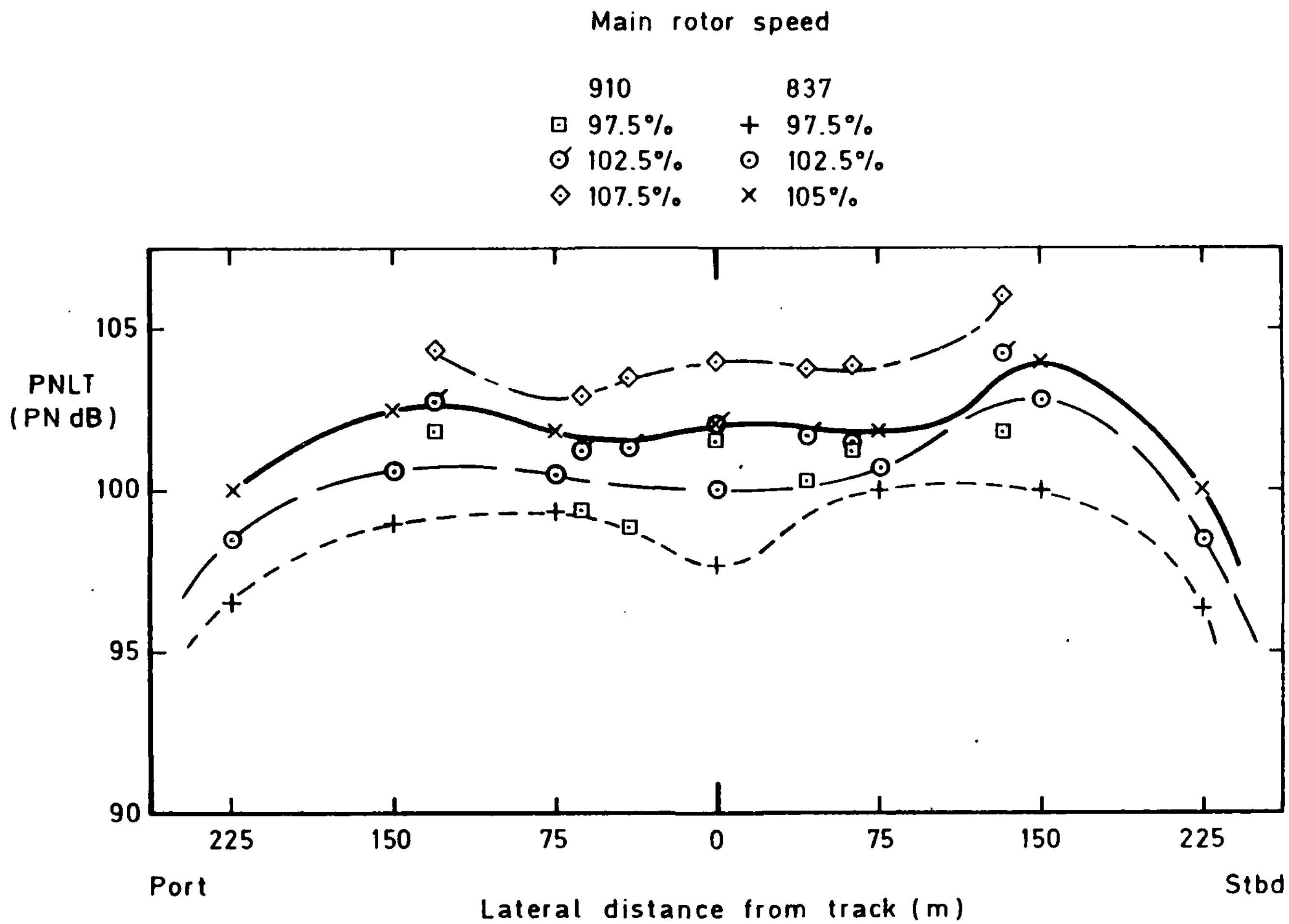

Fig 21d Lateral variation of tone corrected perceived noise level with rotor rotational speed

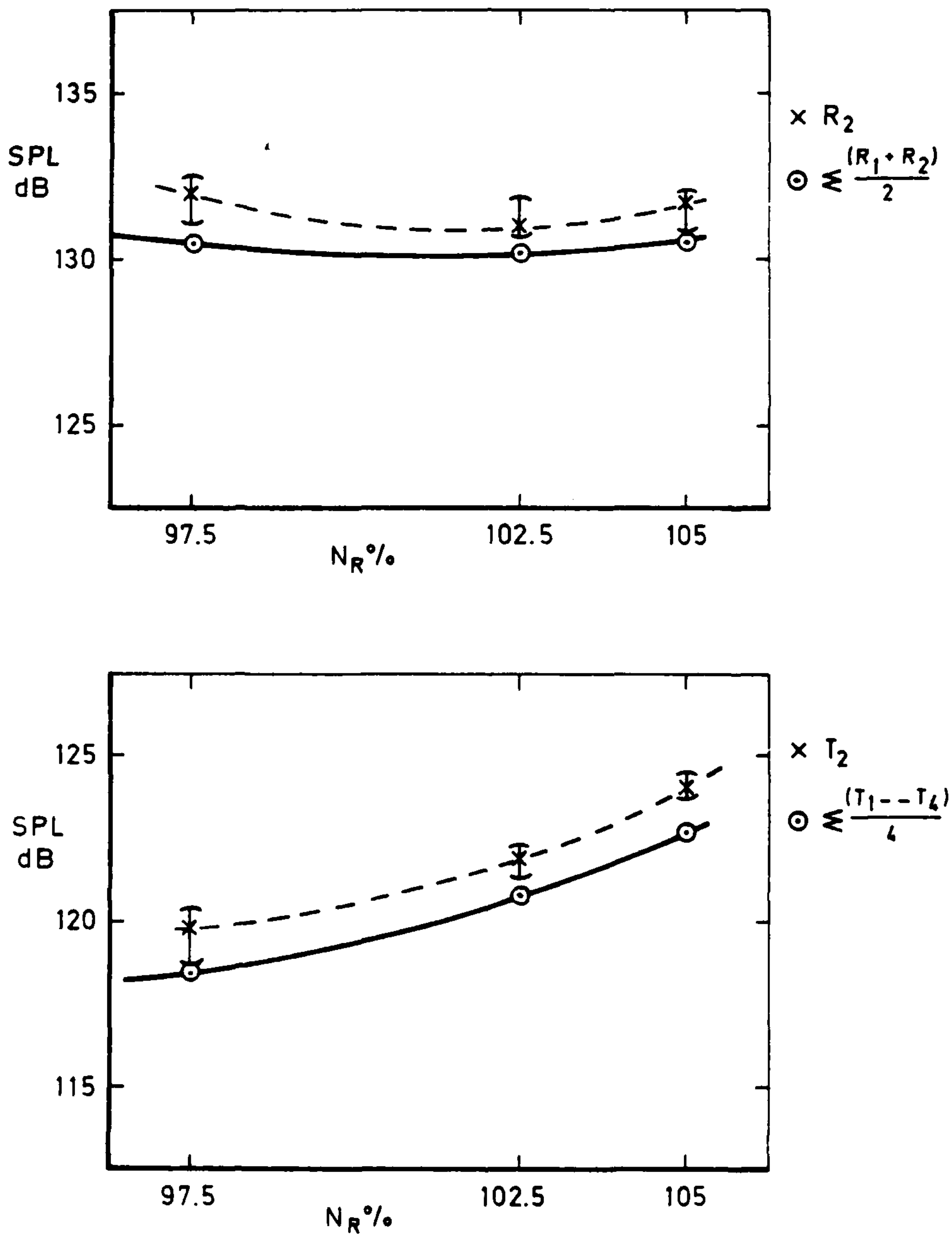

Fig 22 Rotor tone levels from tail-boom microphone

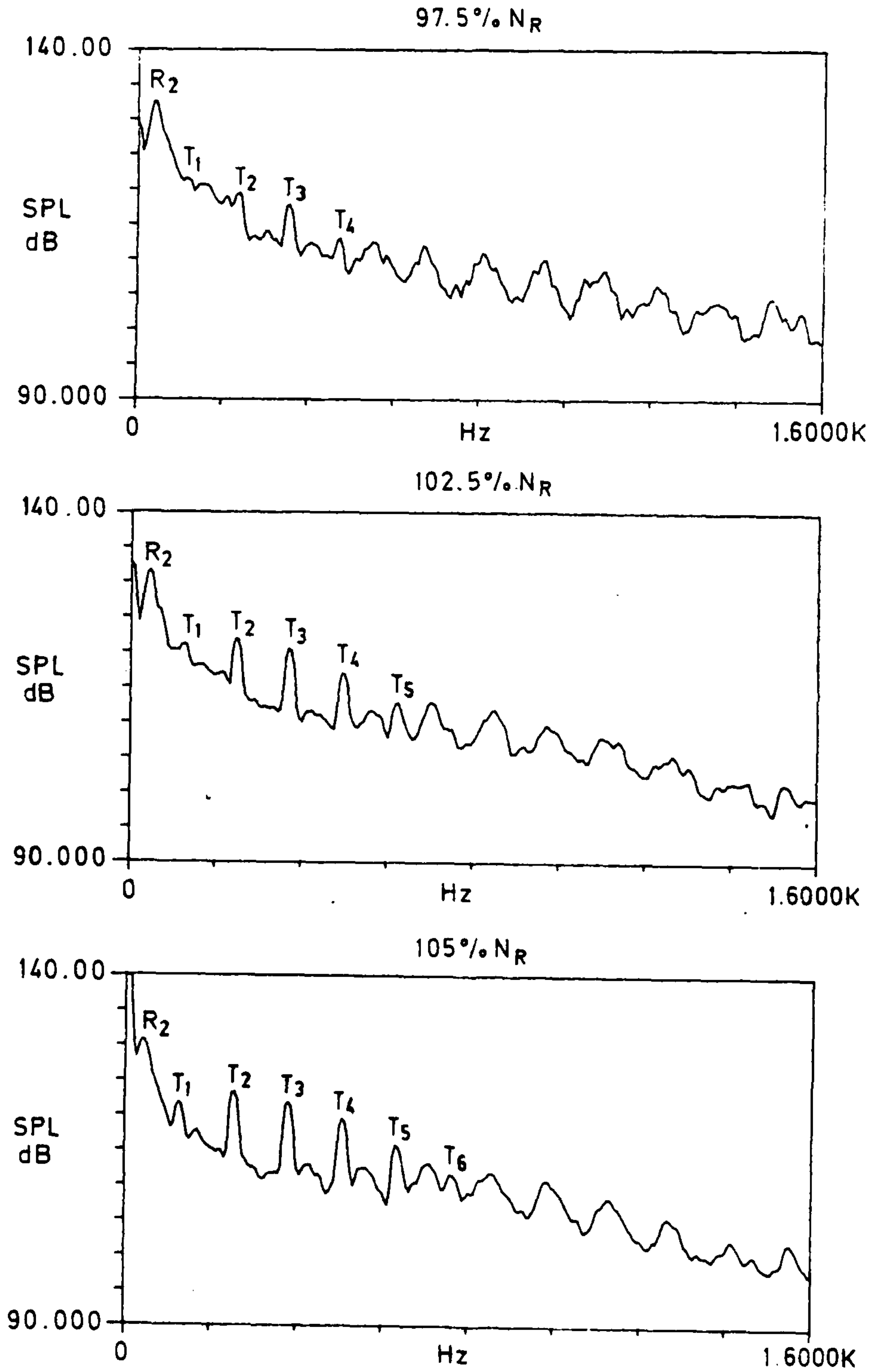

Fig 23 **Narrow-band spectra from tail-boom microphone**

Fig 24a

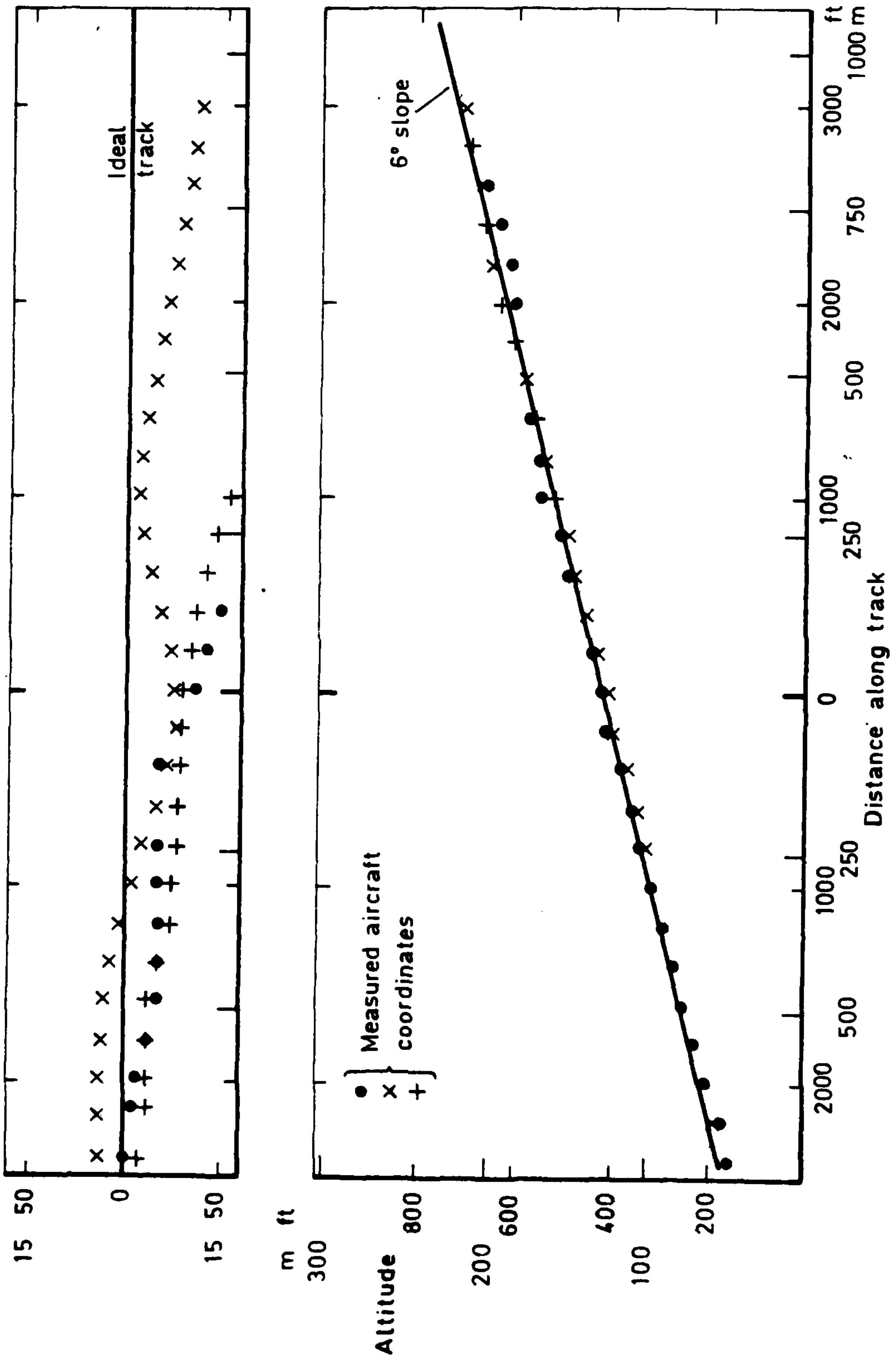

Fig 24a Aircraft flight-path on approach (6°)

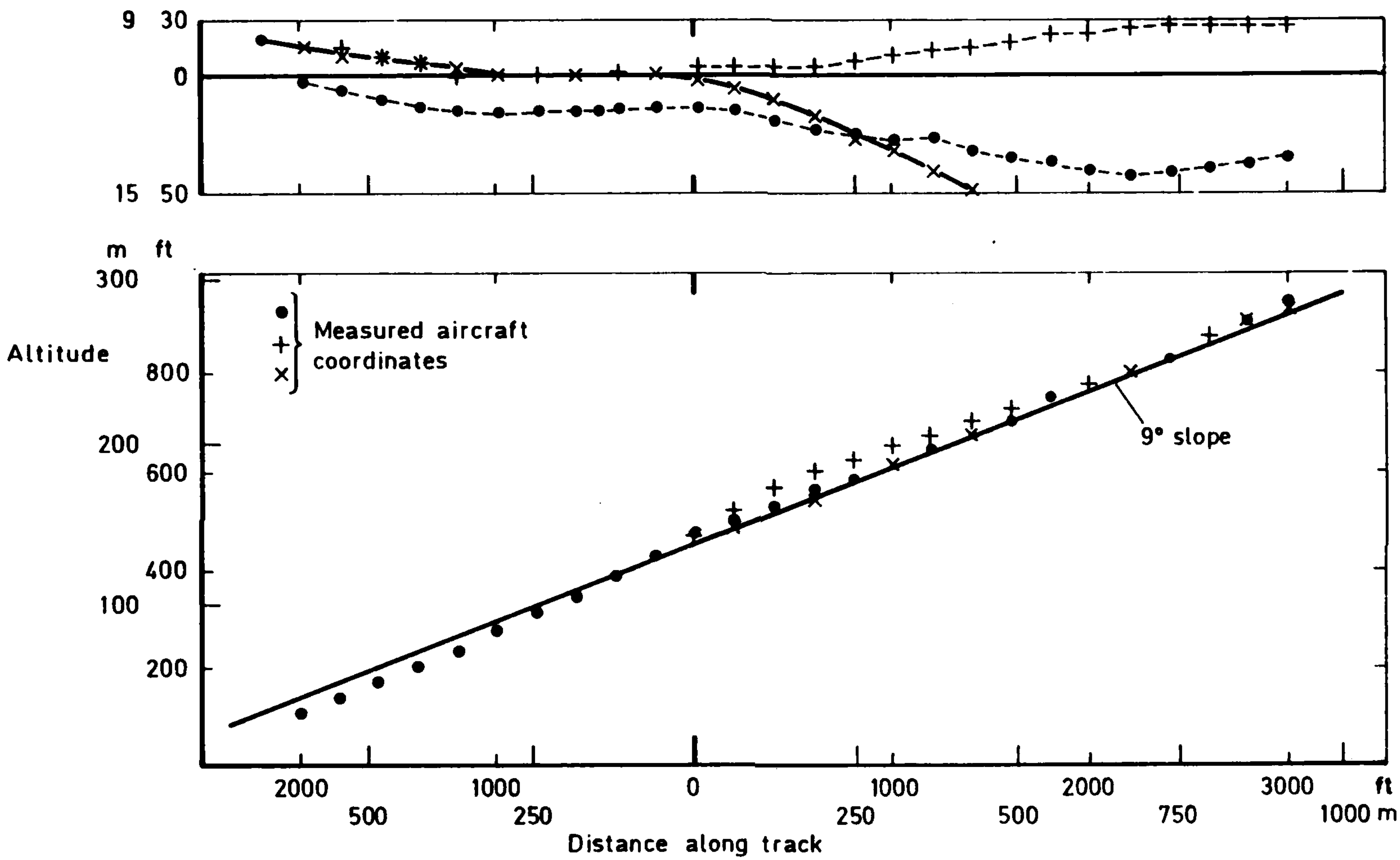

Fig 24b Aircraft flight-path on approach (9°)

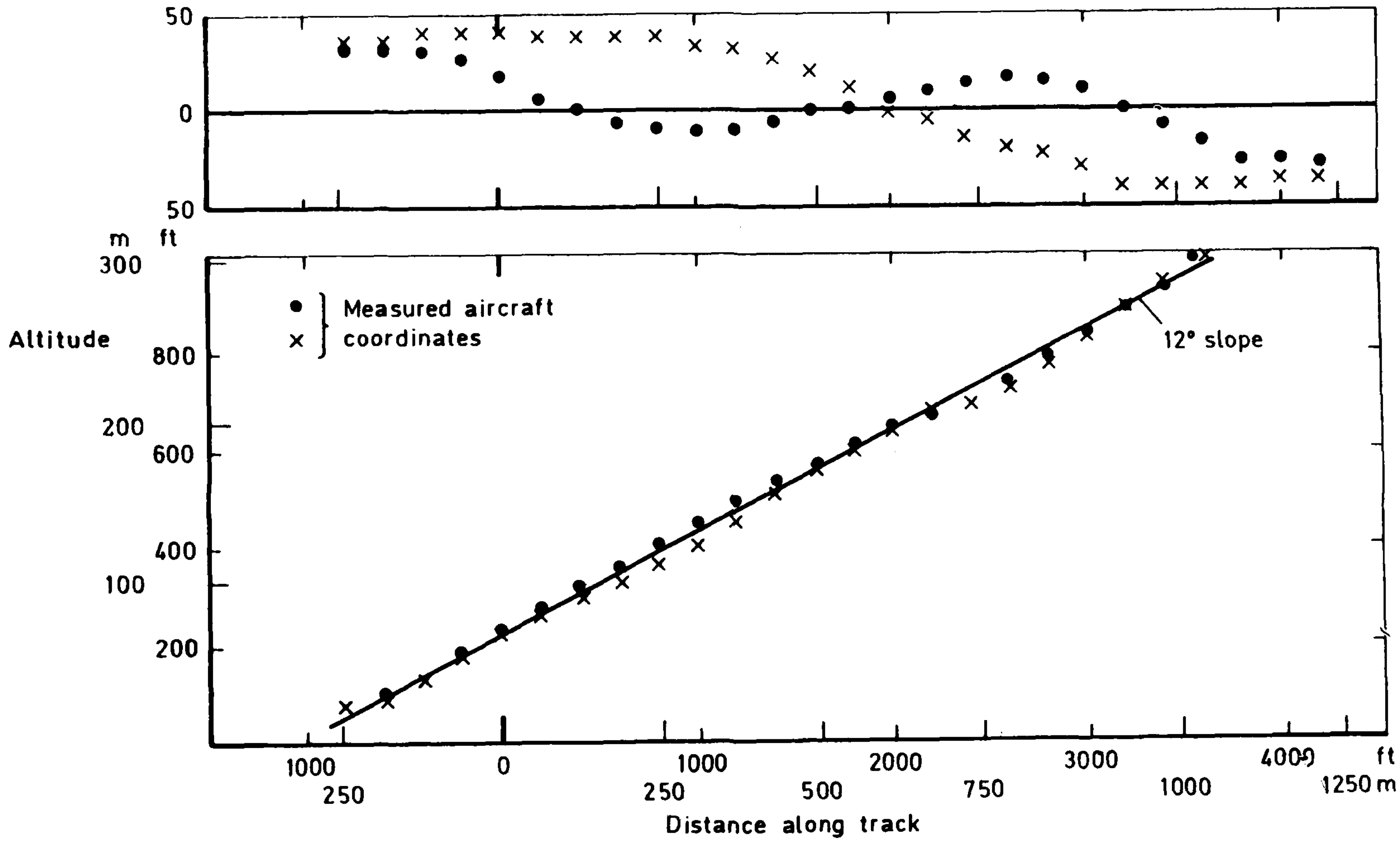

Fig 24c Aircraft flight-path on approach (12°)

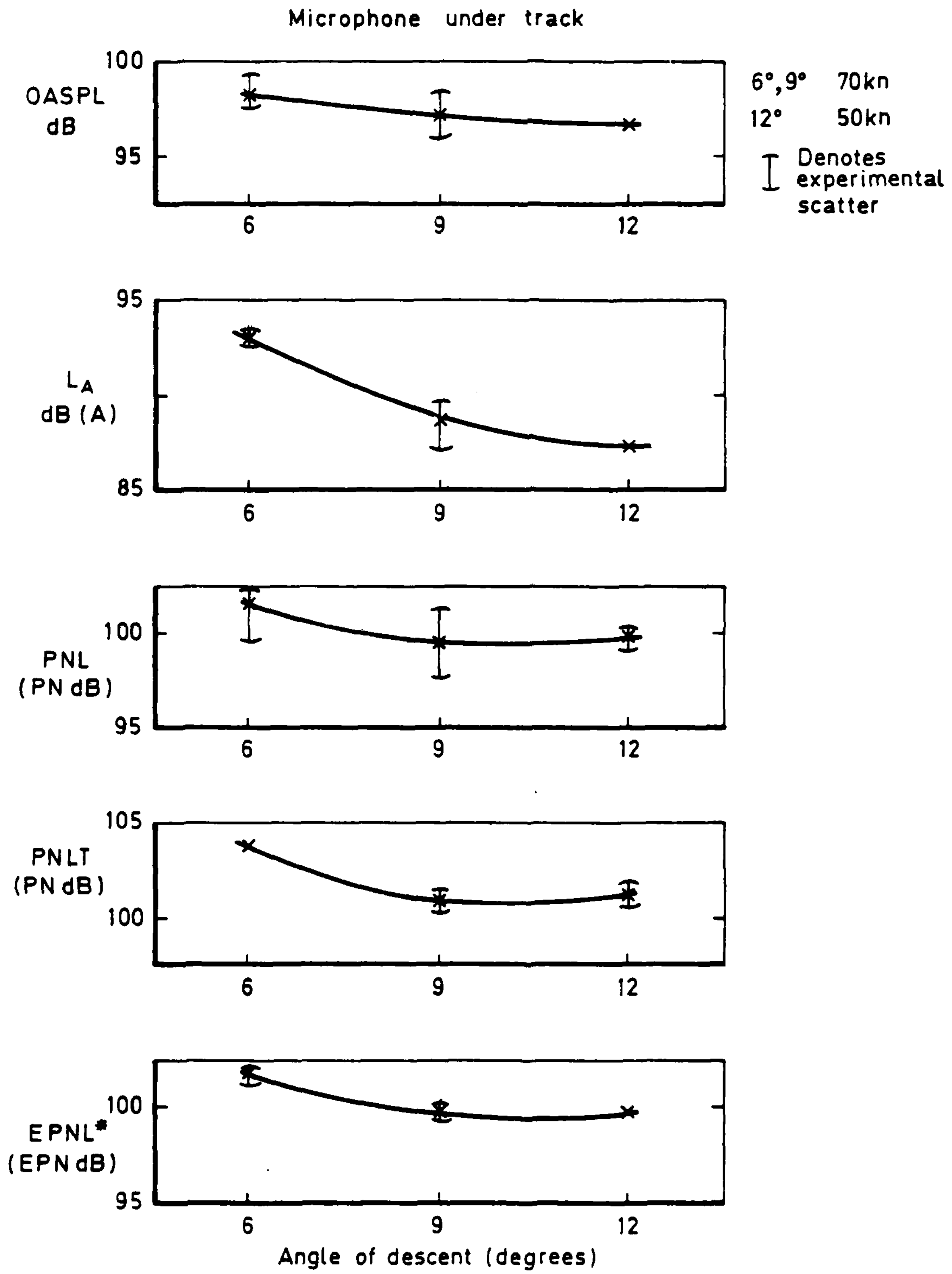

Fig 25 Effect of angle of descent on noise levels

Fig 26

Microphone under track

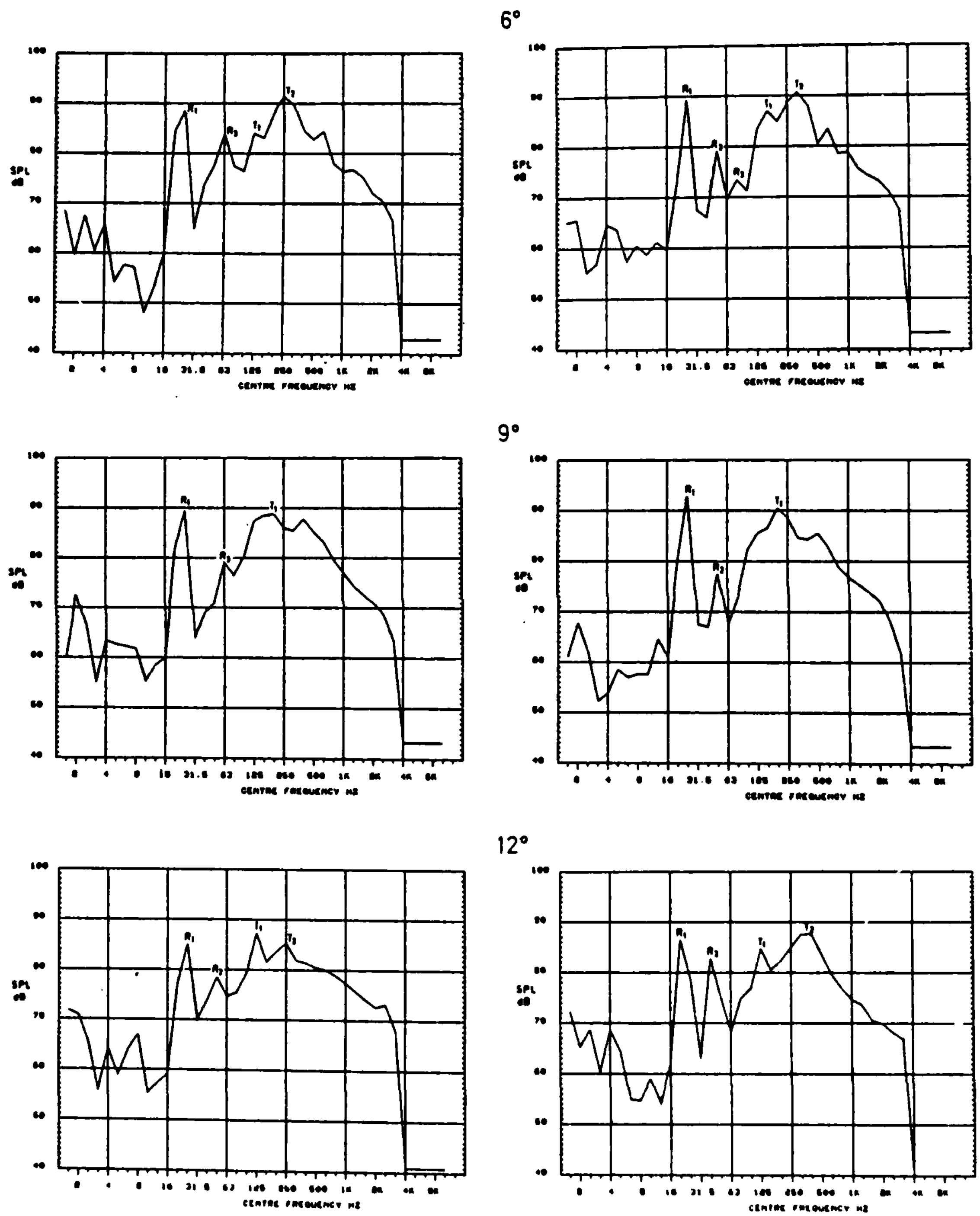

Fig 26 Repeatability and comparison of 1/3-octave spectra at varying angles of descent

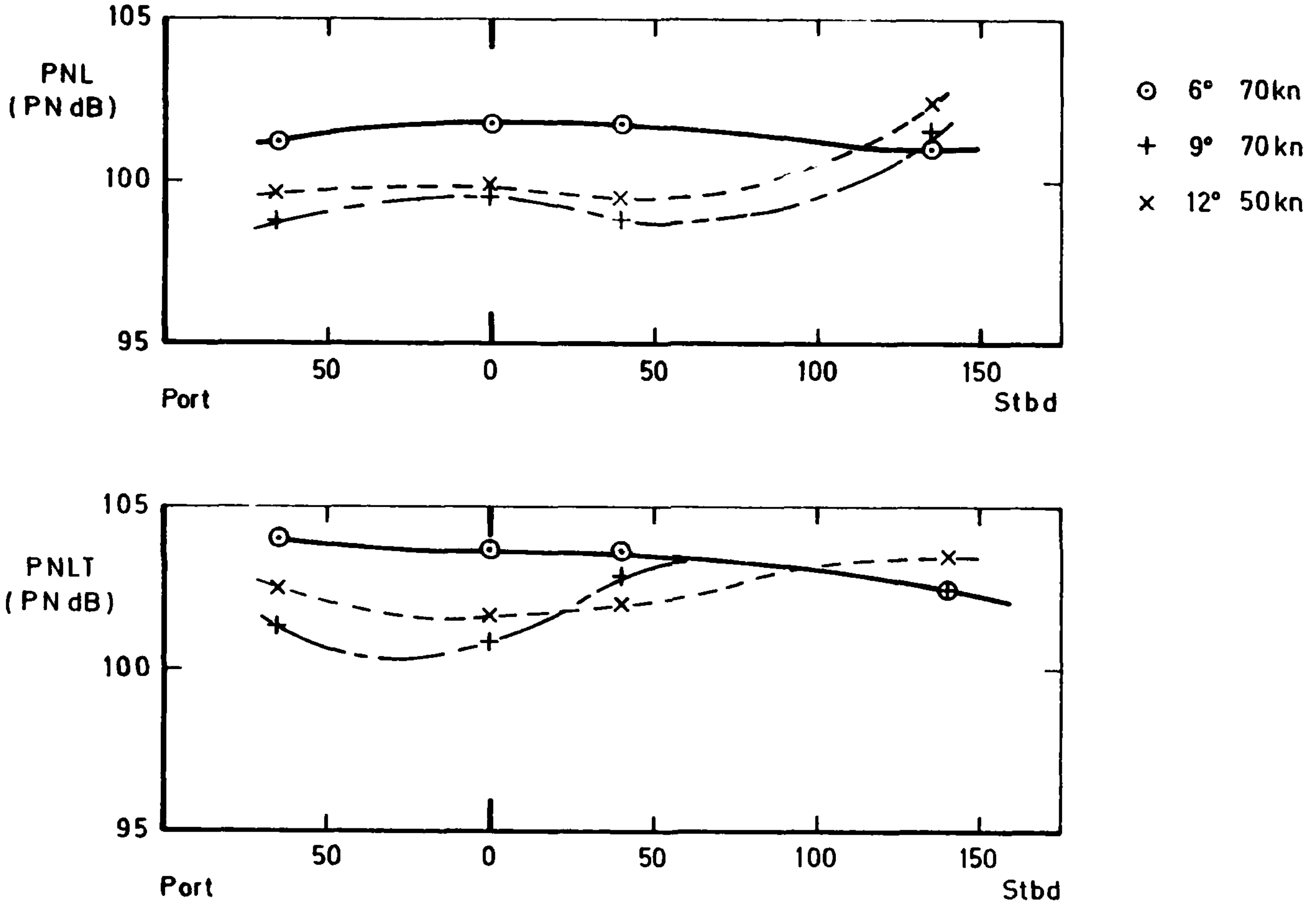

Fig 27 Lateral variation of noise levels with angle of descent

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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17. Abstract

Following on exploratory developments in flight-testing techniques and data-analysis procedures for helicopter external noise, extensive measurements of noise characteristics and associated flight-path data have been made by RAE on several helicopters in various operational modes, with repeated flight trajectories over longitudinal and lateral arrays of ground-based microphones under quiet airfield conditions. This analysis presents some experimental results from Lynx aircraft with standard rotor configurations, being concerned primarily with the influence of different operating procedures on both main-rotor and tail-rotor noise characteristics and on measurement repeatability during level-flight, oblique landing-approach, and oblique take-off. Some tail-rotor near-field noise signatures have also been derived for correlation purposes, using a microphone mounted with a forward-facing nose-cone just outside the fuselage skin on the tail-boom.

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